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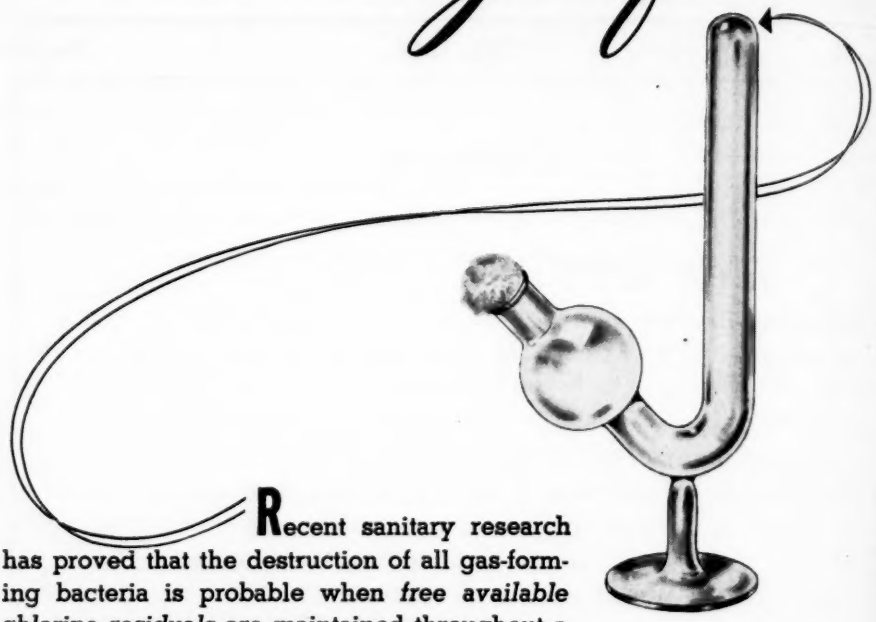

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Vol. 37 June 1945 No. 6

Recent Hurricane Experiences in the Northeast

By Reeves Newsom

Village Manager, Scarsdale, N.Y.

Presented on Jan. 17, 1945, at the New York Section Meeting, New York, N.Y.

PROBABLY the most fundamental lesson to be learned from the hurricane of September 1944, particularly when considered in conjunction with that of 1938, is that weather records of 150 to 175 years can no longer be considered long-time records.

Throughout the decade of 1930 the conviction had been growing that records which were started in Revolutionary days were but parts of cycles of perhaps 500 or even as many as 1,000 years. The recurrence of a hurricane coming up the eastern coast to New England, six years after one unprecedented in more than 125 years, put the finishing touch to the evidence that had been accumulating.

The drought of 1930–1931 in many places surpassed all known records. For instance, in Lexington, Ky., eighteen months passed without a continuous rainfall of 1 in. Not only did grass grow on the bottom of two of the four impounding reservoirs during the second season, but that grass burned up from the sun and the continued drought.

In the winter of 1935–1936 all records for the extension of cold into the South went by the boards. A two weeks' average of zero was experienced in the southern tip of Illinois, which is farther south than much of Kentucky, and frost penetrated over 5 ft. in a locality where services are ordinarily laid at 3 ft.

In January 1936 flood records of 175 years standing were swept away in Pittsburgh and the following year the same happened at Cairo, Ill., where for days the waters stood nearly 3 ft. above the top of the dikes surrounding the city—its complete inundation being prevented only by sand bags placed on the dikes as the flood crest approached.

In 1942 concentration of runoff was experienced during flash floods in northeastern Pennsylvania which swept away dams that had stood since the days of early settlers. Runoffs of 2,500 fps. per sq.mi. were indicated—

a figure several times that usually followed in design—thus rendering inadequate the design of a large part of the spillways in this country.

And so our second hurricane must have killed any lingering doubt regarding the lack of significance of our records as long-time ones.

It is possible that we are now in a phase of the weather cycle which will bring hurricanes to the northeastern United States fairly frequently. In any event, as water works operators, we must prepare to keep service in operation with the minimum of outages under such conditions.

What do the recent experiences along the eastern seaboard indicate the greatest weaknesses have been? What then are some of the things that must be done to prevent interruptions to service in the future?

Before attempting to answer these questions, the author will review some recent experiences.

Experiences in Westchester County

In Westchester County the peak of the storm passed through between 8 and 10 P.M. on September 14. A number of rain gages showed totals of from 4 to 5 in. for the 24 hours, including the storm. At the White Plains water plant 4.25 in. fell between 4 P.M. and midnight. The recording gage at the Scarsdale village hall showed a total of 4.95 in. for the day of the storm of which 4.85 in. fell between 5 P.M. and 11 P.M. The greatest concentration occurred between 6:00 and 6:20 when 0.65 in., at a rate of 1.95 in. per hour for twenty minutes, fell. Flooding, therefore, was not a serious factor in the storm's destructive efforts.

However, wind velocities of from 80 to 95 mph. were reported. In the county thousands of trees were uprooted and, in falling, broke an undetermined number of power and telephone lines, including at least 200 mi. of main power lines. The utility companies and the highway departments of cities, towns and county, generally, reported the conditions to have been worse than in 1938. The worst damage, as reported to the Zone Co-ordinator of Mutual Aid for Water Supplies, took place in Mt. Vernon, New Rochelle, White Plains and Port Chester, in that order.

Although the damage was greater than in the 1938 hurricane and interruptions to elements of water systems were numerically extensive, these interruptions did not have a serious effect on service to any material number of water users.

The New Rochelle Water Co., Pocantico Division, treatment and pumping plant was inoperative for two days because of lack of power. This plant was formerly diesel operated and would normally have had that power in reserve, but a delay had occurred in obtaining a reduction gear replacement. The Pocantico system, however, was furnished from the Croton Aqueduct by the company's station near Ardsley which usually pumps water to the New Rochelle division.

The Westchester Joint District Mamaroneck plant was without electric power for one day but diesel engines were used with no interruption of service. The Rye Lake plant was also out but the area was served from the Mamaroneck Plant while operating its diesels.

Power was off for one and one-half days at the Larchmont treatment and booster stations but auxiliary units took the load. Power was off for about one day in eight other plants but service was not interrupted, although

in a few cases, there would have been trouble if the outages had continued many more hours. In eight other communities power was off a few hours but elevated storage tided over the period.

Path of Hurricane

The 1944 hurricane pursued a considerably different path north of Long Island from the one in 1938. In the earlier storm the center passed through the middle of Connecticut, the westerly third of Massachusetts and from the southeastern corner to the northwestern part of Vermont and into Canada. Areas to the east of the storm's center were much more seriously affected than those to the west. As a result great damage was done in eastern Connecticut, Rhode Island, eastern Massachusetts and New Hampshire, but eastern New York state was less seriously affected.

The 1944 hurricane center passed off the tip of Long Island and across southeastern Massachusetts and thence out to sea, south of Boston (see accompanying map). In this case the damage in Connecticut was less and that in the Cape Cod and Buzzards Bay areas was much more severe than in 1938.

In Rhode Island, which was near the center of the 1944 storm as it passed, only two plants were seriously affected. At Bristol a low dam separating salty tide water from that being supplied to the treatment plant was overtopped by the high tidal water, filling the reservoir with salt water. At Newport, one plant was without power for three days and auxiliary gasoline engines drove the pumps; at the other plant, steam pumps operated during a twelve-hour interruption of current. Water service was not interrupted at Newport but at Bristol it took 48 hours to restore complete service by constructing a 750-ft. flume from the second reservoir upstream, thus bypassing the salted reservoir.

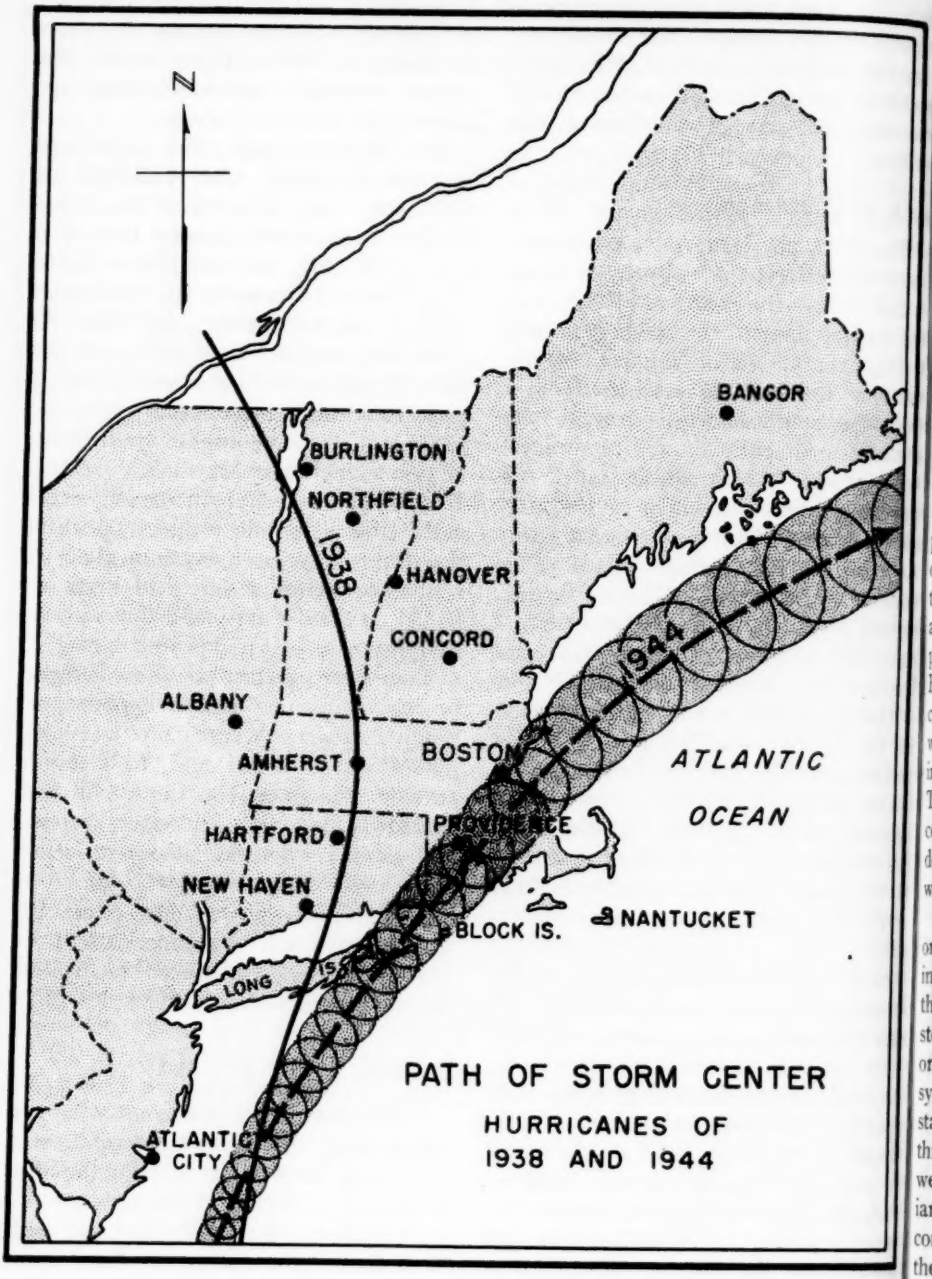
In Massachusetts the hurricane reached its height after midnight of September 14. Reports to the State Health Department showed that at 6 A.M. of the 15th, 36 communities in the Cape Cod and Buzzards Bay area were without electric power, and that 30 other communities scattered over the state to the west of the storm center path were also without current. By 11:15 P.M. the same night, reports from all points, including Martha's Vineyard, Nantucket and Provincetown, indicated that all public water supplies in the state were in operation, that no source of public supply had been affected by flood waters and that in only two instances had mains been damaged.

This was made possible because power companies restored power to pump stations where no auxiliary power was available and, to a larger extent, because in the Cape Cod and Buzzards Bay area all water systems had auxiliary motive power or regularly used diesel engines. Many of these auxiliary power units were installed upon the recommendations of the State Department of Health following the hurricane of 1938.

Lessons To Be Learned

To return to our questions, what are the primary weaknesses and what steps should be taken to prepare for the next hurricane, if and when it comes?

In general, the things to be considered and done fall into three categories: (1) more reliability in sources of power and water; (2) more adequate interconnections between sys-


N
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NORTHFIELD
1938
HANOVER
CONCORD
1944
ALBANY
AMHERST
BOSTON
ATLANTIC
OCEAN
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PROVIDENCE
NEW HAVEN
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PATH OF STORM CENTER
HURRICANES OF
1938 AND 1944
ATLANTIC
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tems; and (3) greater amounts of elevated storage.

Because of the limitations in the opportunities for getting large increases in elevated storage within feasible economic limits that item is discussed first. Obviously, from the viewpoint of the fire underwriters, there is no substitute quite the equal of elevated storage. Water in tanks in the air is ready at all times to start for the place where it is needed without power and without human assistance. But it is equally obvious that when one is considering such relatively flat areas as the greater part of Long Island and Cape Cod it is "not in the wood" to hope for sufficient elevated storage to tide over pumping shut-downs of two or three days. In such locations it is expensive to provide a minimum of elevated storage in amounts approximating 20 to 30 per cent of the maximum daily demand. Even if three or four times that amount could be reasonably provided, the total would not approach that required during even a few days without power. Therefore, elevated storage can be counted on only to tide over shutdowns in the source of power or treated water of relatively short duration.

Most of the successes in preventing or limiting interruptions in service during the recent hurricane were due to the presence of gasoline, diesel or steam-driven auxiliary prime movers or the ability to supply a distribution system from more than one pumping station and source of water. From this the lesson is learned by those who were not so equipped that such auxiliaries are as essential, under hurricane conditions, as the regularly used units themselves.

In one case, that of Garden City, the plant was able to continue to operate and to help out adjacent communities because its power sources were underground from a nearby substation. Such provision is, of course, highly desirable and should be undertaken wherever economically feasible. In most cases, however, pumping stations are quite remote or lie in sparsely developed territory, so that such a requirement would be too costly to be practicable. For years to come the majority of pumping and treatment plants must continue to get electric power from overhead lines. Such power will, therefore, continue to be liable to interruption when high winds uproot trees by the dozens, as will invariably happen in any hurricane.

Auxiliary gasoline or diesel engines or standby steam pumps and boilers will not answer the call successfully when the emergency comes, if they have a relatively small capacity as compared to the regular load. They should be able to pump at least two-thirds of the normal average rate, in which case the usually reduced demand under the conditions following a hurricane and the normal amount in elevated storage will tide over several days when the electric wires may be down. It must be remembered that, while the job of restoring service to any individual plant can be done quickly, following a hurricane, or even a freezing rain storm, the area affected can be very large. The repair crews of the power companies, no matter how efficient, cannot be everywhere at once. Some one has to be last. Therefore, adequate reserve engine capacity must be provided.

Furthermore, it is not enough merely to put in, connect up and then forget about auxiliary installations until the emergency arrives. Such units should be operated under load conditions for a few hours at least once a month.

There are a number of things which can get out of order on such units and gaskets can dry out from non-use. When the pinch comes there is no time even partly to dismantle an engine for repairs.

As was experienced in the last hurricane in at least one case, it may well be impossible to get additional fuel during the emergency. The majority of gasoline pumps depend upon electric power to operate them and the circuit which feeds them will probably not be repaired as rapidly as that going to the water pumping station. It is essential, therefore, that sufficient fuel storage be provided for a number of days, and the more sparsely settled the territory in the vicinity of the station the greater should be such storage.

Under any type of emergency in a water system it is desirable to be able to get water from more than one pumping station or well field. While it is true that a hurricane may put out two or more stations, it is equally true that the more stations one has to carry the whole load the greater the likelihood that one will remain operative. While it is not usual for stations to be connected to more than one source of supply, it sometimes can be done. Furthermore, stations which generally work in parallel from different sources of supply should be equipped to carry the whole load for short periods. In several cases during the 1944 hurricane, the ability to handle the demand from any one of two or more plants was what saved the day.

It should be noted that one water system was subjected to great danger of contamination due to the breaking of a shallow well field suction line by a falling tree. The lesson learned here, therefore, is not to leave sizable trees where they can fall across shallow or exposed pipelines, whatever may be the function of such lines.

The next greatest number of cases where service was preserved following electric power failure was through interconnections to adjacent systems. In some cases water was furnished from one system through a second to a third lying beyond. Certainly a valuable lesson is learned from such flexibility.

It is true, of course, that in the majority of cases effective interconnections are expensive to make. It can be said generally, I believe, that where good sized mains of one system pass through another or cross a large feeder of another, water works men connect their systems. But what of the usual case where the mains grow gradually smaller toward the outskirts of a distribution system, and where it is these small mains that are the nearest to equally small mains of the adjacent community's distribution system? And what of the case where there is an appreciable amount of open country between systems?

First, it can be said that, if a system has an adequate amount of elevated storage and there are chances for a number of even 6-in. interconnections, a great deal can be accomplished in making such storage last by connecting two or three lines. To be sure there must be a proper pressure differential or such a scheme will not work. If the tanks of one system must be substantially emptied before there is a suitable difference in pressure, then small connections are not very effective.

It is the author's belief, however, that the lesson to be learned from the experiences recounted here is that material amounts of money should be spent to bring out to the edge of a distribution system a line or lines large

enough to connect effectively with a similar line in one's neighboring system, which latter, in co-operation, must also be willing to bear the cost of laying an adequate line from its feeder system. Futhermore, lines should be laid across intervening open country at joint expense when the distance is not unreasonable. Such work is a proper item to be included in postwar plans.

In Scarsdale, although we can get water from four separate places, it must be pumped by one of two pumping stations. The village is, therefore, planning the future system to include a 16-in. line from the center of the trunk main system to be available to connect to the junction of two 12-in. lines in the White Plains system, which system has an 8-mil.gal. reservoir at a higher elevation than the top of the tanks at Scarsdale. The village is considering an arrangement of weighted check valves on two metered cross-connections between a planned elevated tank and one with the same high water line in the New Rochelle Water Company's plant, so that either will automatically feed the other when an emergency arises. Provisions of this type are highly desirable, as has been shown by the experiences in the recent hurricane.

On the side of effective co-operation, the strides that have been taken through the formation of mutual aid plans and organizations should be emphasized. Many of the successful efforts that were made to prevent service break-down were possible because of the defense measures that had been taken and the channels for co-operative effort that had been established for that purpose. These should be preserved in some restricted but basic form for use in natural disasters.

In closing it should be pointed out that another fundamental lesson has been learned from these hurricanes. That is, do not trust your luck too far. Simply because for years no emergency has arisen which has not been met without interruption of service, one is not justified in neglecting to take all reasonable and practicable steps to meet a still greater emergency that yet may come.

Revocation of WPB Restrictions Affecting Water Utilities

The War Production Board is going ahead rapidly on removing various restrictive orders. All wartime restrictions established by the following five orders already have been revoked:

L-39, affecting fire hydrants
L-154, Schedule 1, affecting water meters
L-211, affecting steel pipe
L-252, affecting valves
M-9-c-4, affecting copper pipe and tubing

Hurricane Experiences in Nassau County

By J. Lloyd Barron

Former Director, Div. of Sanitation, Nassau County Dept. of Health, Mineola, N.Y.

Presented on Jan. 17, 1945, at the New York Section Meeting, New York, N.Y.

AFTER approximately 60 hours of heavy rainfall, the hurricane struck Nassau County at about 7:30 on Thursday evening, September 14. Wind velocities of between 75 and 90 mph. developed and persisted for about three hours. The total rainfall preceding and during the hurricane varied between 8 and 9 in. over the county.

Nassau County, lying between the Borough of Queens and Suffolk County, has a population exceeding 450,000 and covers an area of 275 sq. mi. across Long Island. It has 42 public water supply distribution systems which serve 77.5 per cent of its area. Twelve of these systems secure water from adjacent systems. Water is obtained from over 300 wells. Power is supplied over a large area by the Long Island Lighting Co., with its principal plant at Glenwood Landing; by the Queensboro Gas and Electric Co., with a plant at Far Rockaway; and by two municipally-owned plants at Freeport and Rockville Centre.

During the height of the storm, power circuits were generally disrupted by the falling of trees and almost all of Nassau County was without current in lighting circuits beginning at about 8 P.M. The two private power companies reported 60 of 75 major power circuits out of operation during and immediately following the storm.

The Nassau County Department of Health, being the only agency in the county whose police powers give it both responsibility and authority with respect to public water supplies, began a survey early Friday morning to determine the extent of damage and disruption. Of the 30 supplies from which information was then or later obtained, 25 suffered interruptions in electric power supply. Of the remaining five, three depend entirely on diesel or steam power. Of the two unaffected and using electric power, one, Garden City Village, has part of its power cables laid underground. Eighteen of the 30 supplies have auxiliary power or power other than electric. Ten of these use such power regularly.

The interruptions in power supply placed in distress ten of the supplies, one of which had no pressure in extensive residential areas for several hours. Emergency interconnections were used between eleven supplies within the county, seven being on the receiving end. The most satisfactory example of interconnection use involved Garden City Village which delivered water to the West Hempstead Water District and to Mineola, the latter in turn supplying Garden City Park and the Willistons.

The system of emergency interconnections in Nassau County was studied by the county health department preliminary to the establishment of the state mutual aid plan and the system was greatly extended during 1942 and

1943. These 95 permanent connections between distribution systems definitely proved their worth in this emergency. Even those not used represented the finest kind of insurance to local water superintendents and many more would have come into use if the power failures had been prolonged.

In the case of the Hicksville Water District, with all wells electric powered, the power went off early Thursday evening and water was obtained Friday morning from the Jericho Water District, which was also without current or auxiliary power. Jericho, in order to protect its storage reserve, had to cut Hicksville off at noon. The Meadowbrook County Hospital has a 50,000-gal. elevated storage tank supplied from Hicksville, and the health department thereupon notified the hospital to close the valve on the supply line in order to retain its water in storage for hospital use.

Late on Friday afternoon, a distress call from Hicksville led the health department to arrange with the Grumman Aircraft Engineering Co. at Bethpage for a temporary connection. This was accomplished by two lines of fire hose to a valved-off section of the Central Park Water District main and thence through an existing interconnection to the Hicksville system. This connection was in use from 8:32 P.M. Friday to 4:15 A.M. Saturday and delivered about 500 gpm. This emergency arrangement could have been avoided if proper liaison had been maintained with Jericho where power was restored at 7 P.M. Friday. However, all telephone lines were down and the health department maintained communication through police radio cars.

The Citizens Water Supply Co. supplies the Great Neck and Kings Point areas and is wholly dependent on electric power. This power was off from Thursday evening until about 6 P.M. Friday. On Friday an interconnection with the Manhasset-Lakeville Water District was used to keep some pressure in the lower areas of the Great Neck system, although the pressure differential against the lower Manhasset-Lakeville system made it impossible to maintain pressures in the high Kings Point area.

Just before the hurricane, the Citizens Water Supply Co. had installed a chlorinator at its main station under an order of the county health department. This requirement had been imposed because the supply at this station is secured in part from a shallow well field with extensive surface suction lines located in the delta of a small stream discharging to Little Neck Bay. Our concern had been with the possibility of corroded well casings or leaky suction lines admitting surface water which could not have been readily detected until damage might have been done.

On Friday noon, the author visited the pump station and left instructions that, upon resumption of pumping, the new chlorinator was to be turned on at maximum dosage and so operated until all conditions had returned to normal. It was not until several days later when the health department learned that a large tree in the well field had been blown down, and its roots had displaced a suction line which admitted surface water in quantity. Since no gastro-enteritis was reported from this area, it is to be assumed that the installation of this chlorinator was justified on its very first use.

Another interesting byproduct of the storm came to light at the Village of Freeport. The storm followed a very long period of no rainfall, broken by

the unprecedented precipitation accompanying the hurricane. The local water superintendent, Alvin G. Southard, had recently been instrumental in initiating a sampling routine through contract with a private laboratory, and a set of samples had been collected during the heavy rain and just before the hurricane on Thursday. The laboratory results were reported after the hurricane and indicated extensive coliform pollution of the system. Recheck samples were immediately obtained which showed that the contamination had diminished but was persisting, especially in the extremities of the system, indicating that the bacteria-laden water was being displaced by clean water from the well sources.

Theories as to sources of the pollution were carefully checked and eliminated, including the calgon solution (sodium hexametaphosphate), the possible surcharging of a storm drain close to one of the wells, cross-connections at the power plant, etc. Finally, the assistant sanitary engineer of the health department, Arthur H. Herberger, climbed to the top of the modern, elevated, million-gallon steel storage tank and there discovered an obvious but disconcerting explanation of the trouble.

This 175-ft. tank, in the top of which the water is aerated, has a solid steel roof shell with a channel iron forming a gutter completely around its outside lower rim. Immediately below the gutter is a ventilating opening clear around the tank, properly closed with a heavy copper mesh screen. However, the roof and gutter are of such diameter as to fit inside the vertical tank wall and screen. Consequently, the gutter, with holes drilled every foot, discharged the roof drainage directly into the stored water rather than to the outside walkway.

Freeport has its quota of pigeons, starlings and dust-laden atmosphere and it is to be presumed that a good many pounds of bird manure accumulated on the tank roof and gutter during the dry period. This was suddenly and thoroughly washed into the tank by the heavy rains preceding the sampling and was carried throughout the distribution system. Such contamination had no doubt occurred many times before, but the sampling was so infrequent that it had not been revealed.

This sanitary defect was promptly remedied by plugging about two-thirds of the gutter holes and bushing in drainage pipes to the remaining holes. The pipes were bent with an offset so as to pass through cuts in the wire screen and discharge onto the walkway. The tank was then thoroughly disinfected with chlorine, emptied, refilled, again chlorinated, refilled and returned to service.

A somewhat similar instance of contamination was discovered at Williston Park following the storm. Distribution system samples showing coliform organisms led to an investigation which indicated the possibility of avian pollution. When the roof of the elevated storage tank was examined, it was found that the force of the hurricane had apparently thrown the hinged hatch cover open and made the interior of the tank accessible to birds for a period of several weeks, thus accounting for the pollution in the distribution system.

It was in the areas of Nassau County where public water supplies are not yet provided, that the principal hardships were experienced. Here, household

were dependent on electric current not only for the operation of private well pumps but for water with which to drink and cook, to flush toilets and to fill furnaces and hot water tanks. The lighting companies were inclined to center efforts in the restoration of residential circuits to the more densely settled areas where water supply, being public, was not a problem. Consequently, there were many scattered residences, amounting to many hundreds of families, who were without power, water and sanitary facilities for over two weeks. It is the opinion of the health department that, in another similar disaster, the county commissioner of health would declare an emergency under his special police powers and issue an order upon the power companies requiring them to give priority, in the restoration of local circuits, to private water supply areas over those having functioning public water supplies.

From the health department point of view, public water supply in this instance was only one of many emergency problems. The early Friday morning survey revealed only six milk pasteurizing plants out of 24 able to operate. Refrigeration was off, not only in homes, but in large and small food stores all over the county, necessitating quick action by department inspectors to get natural and dry ice supplies into use wherever possible and, later, to condemn perishable foods, especially frozen foods and ice cream stocks. Sewage treatment plants and pumping stations suffered just as immediately as water supplies, but were considerably lower in order of priority in having power restored. The health department even had one very sharp complaint from an annoyed citizen who couldn't operate his electric razor.

Relations with the power companies were close, co-operative and mutually helpful. After the storm, however, it was necessary for the health department to remind some water superintendents of their obligations under the state sanitary code to report to the health authority all emergency changes affecting the sources or quality of their respective water supplies. Some failed to realize that the health department, with an over-all engineering view of the situation, was able to give needed direction in the use of interconnections and in the public health aspects of other emergency measures, and to share somewhat the heavy responsibilities which fall upon water superintendents in time of disaster.

This hurricane and its predecessor of 1938 have provided quite a reservoir of experience in dealing with emergencies and in revealing the advantages of preparatory measures and thorough co-operation on the part of water supplies, power sources and health and other public officials.

For a description of hurricane experiences in Massachusetts and Rhode Island readers are referred to the abstracts on pp. 593–594 of this issue.

Interruptions in Electrical Supply Along New Jersey Shore During 1944 Hurricane

By Robert M. Cadman

Supt., Eng. Dept., Schedule Rating Office, Newark, N.J.

Presented on Nov. 4, 1944, at the New Jersey Section Meeting, Atlantic City, N.J.

FOLLOWING the severe storm of Sept. 14, 1944, it was the author's privilege to make an inspection tour of the various water pumping stations along the New Jersey Coast from Cape May Point to Highlands. A report of the findings is given in tabular form on the following pages.

In view of the experiences at these various plants the following recommendations are suggested, which, if followed, should materially reduce the probability of interruptions to water service in the event of another such storm.

1. Emergency connections should be made with adjoining municipalities where practical.

2. In case of emergency, when cross-connections are not available, 2½-in. hose lines should be laid from hydrant to hydrant in adjoining municipalities, preferably using an OCD or a fire department pumper as a booster.

3. OCD or fire department pumpers should be used to pump water from suction reservoirs into water mains when the regular high-lift pumps are out of service.

4. Adequate cooling water should be provided for internal combustion engines under all conditions.

5. Storage batteries should be kept at full charge at all times when they are to be used for starting gasoline engines for emergency use.

6. Standby units, when provided, should be started once each week.

7. When used for emergency pumping, steam should be kept at at least one-half the required working pressure, or the fire should be laid ready for lighting.

8. Where electric current is normally used for pumping, at least two separate sources of electric power should be provided, one of which should preferably be a gasoline- or a diesel-driven generator.

9. Where pressure recording gages are provided, they should be of the hand-wound variety so as to eliminate breaks in the continuity of the records.

10. Where coal, gasoline or oil are used in an emergency, at least a five-days' supply should be provided.

11. Where gasoline or oil is used for fuel for internal combustion engines, at least two methods should be used for delivering the fuel to the engine.

12. Where hydrants are installed near boardwalks or other structures that are liable to be moved in case of storms, they should be protected in a suitable manner either by steel rails set in concrete or by using hydrants with a weak joint in the barrel, the lower section to be set in concrete.

13. Where gasoline- or diesel-driven generators are not available for supplying electric power, auxiliary right-angle drive, gasoline-engine-driven pumps should be installed for deep well pumping, and auxiliary gasoline-engine drive should be installed for high-lift pumps taking suction from reservoirs.

Location	Source of Supply and Power	Damage to Services	Current Off	Remarks
Allenhurst	*Domestic system*—22 fire hydrants. Supplied from three wells by air lift, discharging to 95,000-gal. collecting basin. Water repumped to distribution system with 250,000-gal. elevated tank as equalizer. One centrifugal pump belt driven by diesel engine which is also directly connected to electric motor; one air compressor directly connected to electric motor. Two 250,000-gal. capacity pressure filters. *Fire system*—Supplied from Deal Lake which has ample capacity. One twin volute pump driven by electric motor automatically started when pressure drops below 41 lb. One centrifugal pump driven by electric motor manually operated, 210,000-gal. standpipe floats on system.	One 1½-in. service broken.		No interruption of electric power and no abnormal drop in pressure.
Asbury Park Municipal System	Four deep wells by air-lift discharge into 205,000-gal. reservoir. One compressor and two pumps electrically driven. One compressor and one pump operated by steam. Three 200-hp. Scotch Marine boilers for 120-lb. pressure. Six 1.0-mgd. horizontal steel pressure filters. Standpipe 125 ft. high and 12 ft. in diameter with capacity of 100,000 gal. floats on system. Two emergency connections with Monmouth Consolidated Water Co., one closed and the other operating automatically. Asbury Park took 11.5 mil.gal. from Monmouth Consolidated Water Co. during summer of 1944.		Short periods.	No services or hydrants broken and no abnormal drop in pressure.

Location	*Source of Supply and Power*	*Damage to Services*	*Current Off*	*Remarks*
Atlantic City	Surface supply from Absecon Creek has minimum runoff of 3 mgd. Upper and lower reservoirs have combined capacity of 500 mgd. Thirteen driven wells equipped with motor-driven deep well pumps. Combined yield is 20.7 mil.gal. Two standpipes with combined capacity at el. 115 equivalent to 520,000 gal. Maximum consumption about 19 mgd.	Three broken h-p. hydrants and several h-p. fire pumps in hotels out of service due to high water.		Pumping station at Pleasantville, 5 mi. north of Atlantic City. Five pumps with aggregate capacity of 62 mgd.; 37 mgd. operated by electricity and 25 mgd. by steam. Two motor-driven and one steam-driven exciters and steam-turbine-driven 300-kw. generator. Latter standby unit. Normal operation by electricity; current purchased. Two circuits constantly charged at switchboard and power from third quickly available. Steam equipment ready to operate and full pressure maintained in one boiler. Current purchased locally but 2-mgd. pump at Well No. 2 can also be operated from generator in pumping station. 6-in. emergency connection with Ventnor City and 8-in. with Pleasantville. During storm pressure dropped from normal of 40–47 lb. to minimum of 29 lb.
Atlantic County Water Co.	Four pumping stations, all operated electrically except Bargaintown Station which has one 2-mil.gal. centrifugal pump driven by 4-cylinder gasoline engine.		5 hr. 40 min.	Lowest pressure recorded during storm was 24 lb.
Avalon	Two wells operated by air lift and one by electrically-driven deep well pump.	Eight broken services.	43 hr.	Pressure in 125-ft. standpipe did not fall below 32 lb.

Location *Source of Supply and Power* *Damage to Services* *Current Off* *Remarks*

Location	Source of Supply and Power	Damage to Services	Current Off	Remarks
Avalon	Two wells operated by air lift and one by electrically-driven deep well pump.	Eight broken services.	45 hr.	Pressure in [illegible] did not fall below 32 lb.
Avon	Two deep wells by electrically-driven well pumps. Water discharged directly into distribution system with 200,000-gal. elevated tank as equalizer. 8-in. closed emergency connection to the Monmouth Consolidated Water Co. system at Bradley Beach.			No interruption of electric service and no broken mains, services or hydrants. No abnormal drop in pressure.
Barnegat	Two gasoline-engine driven pumps and one electrically-driven pump. 50,000-gal. elevated tank.		65 hr.	Although electric current was off 65 hr. there was normal supply of water available due to gasoline-powered equipment.
Beach Haven	Three deep wells, all electrically driven except one low-lift and one high, which are gasoline driven. Elevated tank of 100,000-gal. capacity.	25–30 broken services.	21 hr. 45 min.	During time current was off pressure dropped to zero.
Beachwood	One electrically-driven pump. 50,000-gal. elevated tank.			No interruption of electric service.
Belmar	Ten deep wells. One pump and one compressor operated by diesel engine and one pump and one compressor operated by steam. Rest of pumps and compressors driven by electric motors. Two boilers, one of which is kept fired at all times. 4-in. metered emergency connection with Monmouth Consolidated Water Co. in Neptune City. 238,000-gal. standpipe.	One hydrant broken.	9 hr.	No abnormal reduction in pressure.
Brielle	Two wells by two low-lift and two high-lift electrically-driven pumps. One 35-kw. a-c. generator driven by 45-hp. gasoline engine operates pumps. 100,000-gal. elevated tank. Closed 8-in. metered connection with Manasquan.		19 hr. 30 min.	No abnormal drop in pressure observed. No broken services, mains or hydrants.

Location	*Source of Supply and Power*	*Damage to Services*	*Current Off*	*Remarks*
Brigantine City	Two electrically-driven deep well pumps. Two elevated tanks of 100,000- and 75,000-gal. capacity Latter shut off and kept in reserve for possible fire during storm.	27 broken services and one broken 8-in. main.	48 hr.	Pressure on system dropped from 55 lb. to zero. Bridge from Atlantic City to Brigantine City carried away during storm.
Cape May City	Diesel-driven generators.	Because of broken hydrants near boardwalk, impossible to keep 700,000-gal. elevated tank full.	5 hr. 45 min.	City without water for 6½ hr. Necessary to shut down diesel engines because of lack of cooling water.
Cape May Court House	Two electrically-driven pumps and one gasoline-engine-driven pump.		26 hr.	Impossible to start gasoline engine because battery was down. Water in 50,000-gal. elevated tank exhausted by time new battery serviced and no cooling water available.
Cape May Point	Electrically-driven triplex pump. Gasoline-engine pump for emergency use.	One 4-in. main and two house services shut off.	4 hr.	Water in 100-ft. standpipe never dropped below 40-ft. level. Gasoline unit not used.
Harvey Cedars	One electrically-driven pump and one gasoline-driven pump for emergency use.	100 broken services and one broken hydrant.	43 hr.	Pressure from 145,400-gal. standpipe dropped to zero.
Highlands	Three wells. Water raised by three deep well pumps and discharged into two 500-gpm. slow sand filters, whence it flows by gravity into suction basins and is pumped from there to distribution system with standpipes, with aggregate capacity of 374,640 gal., as equalizers. Three low-lift and two high-lift pumps all electrically operated.	40 broken services.	48 hr.	Borough without water for 1¼ hr.

Location *Source of Supply and Power* *Damage to Services* *Current Off* *Remarks*

and two high-lift pumps all electrically operated.

Location	*Source of Supply and Power*	*Damage to Services*	*Current Off*	*Remarks*
Island Heights	One electrically-driven and one gasoline-engine-driven pump.		1 wk.	Not less than three-fourths of normal elevated storage available during storm.
Lavallette	Two deep wells. One operated by electricity, other by either electricity or gasoline engine. There is an emergency connection with Dover Township.		26 hr. 10 min.	Practically full standpipe of 158,000 gal. maintained during storm.
Long Beach Township	Electrically-driven air compressor and pump.	60 broken services.	24 hr. 30 min.	When pressure dropped to 20 lb. 115-ft. standpipe shut off to save water for emergency use. Fire occurred during storm and was extinguished.
Manasquan	Five wells. All pumps and compressors driven by electric motors except one compressor and one pump driven by gasoline engine. Standpipe of 152,000-gal. capacity.			Lowest pressure recorded 18 lb. Electric recording gage was out of service. Considerable difficulty experienced in starting gasoline engine because of run-down battery. Lack of adequate cooling water and trouble in connection with fuel supply to engine experienced. 8-in. and 6-in. emergency connections with Brielle and Sea Girt not used.
Margate City	Three electrically-driven deep well pumps with combined yield of 2.45 mgd. Two deliver either to suction wells or to distribution system and third to suction wells only. Three electrically-driven high-lift pumps with combined capacity of 3000 gpm. and one 1000-gpm. pump driven by 75-hp. gasoline engine. High-lift pumps take suction from 2 reservoirs with combined capacity of 455,000 gal.	Three broken services.		90,000-gal. standpipe had minimum of 30,000 gal. storage during storm. Margate City supplied Longport through 8-in. emergency connection.

Location	*Source of Supply and Power*	*Damage to Services*	*Current Off*	*Remarks*
Monmouth Consolidated Water Co.	Water obtained from four stations—Newman Springs Station in Middletown Township, West End Station in Long Branch and Jumping Brook and Whitesville Stations in Neptune Township. In addition, one booster station supplying high areas in Middletown Township. Newman Springs in continuous operation. Operated during summer by steam and rest of year by gasoline and electricity. West End operated during summer and used as standby station during rest of year. When pressures drop below 50 lb., siren automatically operated notifying station engineers and gasoline pumps immediately started. Jumping Brook operated during summer for about 16 to 20 hr. per day. Whitesville operated only during summer.	Five broken services, two broken hydrants and one broken 6-in. fire service.	15 hr. at Jumping Brook. 15½ hr. at Newman Springs	Company owns and operates supply works distribution system and appurtenances supplying water for domestic and fire protection purposes to Long Branch, Fair Haven, Sea Bright, Monmouth Beach, Eatontown, West Long Branch, Deal, Oceanport, Ocean Township, Bradley Beach, Neptune City, Neptune Township, Little Silver, Shrewsbury, Interlaken, Ocean Grove, Rumson, Middletown Township, sections of Asbury Park west of railroad and sections of Shrewsbury Township adjacent to Shrewsbury Borough. In addition there is 4-in. metered connection to Belmar system and 8-in. closed emergency connection to Red Bank system; 10-in. closed connection and two 6-in. metered connections to Asbury Park system. Two sources of electrical energy provided for Newman Springs Station and during storm both out of service. Greatest drop in pressure at Jumping Brook between 6 and 7 A.M. on Sept. 15. Reading was 40 lb. as compared to 65 to 75 lb. normal pressure.

Location	*Source of Supply and Power*	*Damage to Services*	*Current Off*	*Remarks*
Ocean City	Five pumping stations, all operated electrically except No. 1 which has both steam- and electrically-operated pumps.	100 broken services.	3 hr. 45 min.	During time current was off 3-mil.gal. steam pump operated together with 1050-cfm. steam air compressor. Lowest pressure recorded during storm was 12 lb.
Ocean County Water Co.	Four wells in Bay Head and four in Mantoloking. At Bay Head one pump and two compressors operated by gasoline or gas. All other pumps operated by electricity. 58,000-gal. elevated tank in Bay Head.	25 broken services. System without water for 4 hr.		Supplies Bay Head, Mantoloking, and parts of Dover and Brick Townships. Water obtained from Point Pleasant Beach through two 2½-in. hose lines stretched from hydrant to hydrant.
Ocean Gate	Two electrically-driven pumps. Gasoline-driven generator in reserve to furnish electric power. 100,000-gal. tank on 100-ft. tower.		7 hr. 30 min.	Lowest pressure recorded during storm was 45 lb.
Point Pleasant Beach	Air lift from eight deep wells. One 280-hp. diesel engine directly connected to 250-hp. generator supplies current to operate six pumps and three compressors. Standby connection from Power and Light Co. Elevated tank has capacity of 250,000 gal. and standpipe 212,000 gal.		11 hr. 30 min.	Elevated storage was at normal level throughout storm.
Point Pleasant Borough	One 10-in. and one 8-in. deep well. Water pumped directly into system with 200,000-gal. elevated tank as equalizer. Equipment consists of two 50-hp. diesel engines, each driving 250-gpm. deep well pump. A pump and engine are housed in each of two stations.			There is no record of interruption of electric service and pressures were maintained as usual.

Location	*Source of Supply and Power*	*Damage to Services*	*Current Off*	*Remarks*
Sea Girt	Three wells. Three low-lift, two domestic high-lift and one fire pump, all operated by electric motors. One 75-kva. a-c. generator driven by 210-hp. gasoline engine. Generator operated monthly and current normally purchased from Power and Light Co. 150,000-gal. elevated tank and a closed emergency connection to Manasquan distribution system.	Two hydrants broken.	91 hr.	Pressure on system dropped to zero. 75-kva. generator used during emergency.
Sea Isle City	Two pumping stations. All equipment electrically operated except 350-gpm. triplex pump driven by 27-hp. gasoline engine and 8 × 10-in. electrically- or oil-engine-driven air compressor.	500 house services broken.	48 hr.	125-ft. standpipe cut off at 40 lb. and contents reserved for possible fire protection.
Seaside Heights	Two electrically-driven pumps. 120-ft. standpipe.		24 hr.	6-in. emergency connection with Seaside Park was open for about 3 hr. Lowest pressure recorded 26 lb.
Seaside Park	Electrically-driven pumps. Two diesel-driven generators, each of which can supply necessary power. 100,000-gal. elevated tank one-quarter full at lowest stage on Sept. 15.		21 hr. 55 min.	Water supplied to Seaside Heights for 3 hr. on Sept. 15.
Ship Bottom	Electrically-driven pumps. 172,000-gal. standpipe.	One 6-in. main and 30 services broken.	24 hr. 5 min.	Pressure dropped to zero.
Spring Lake	Three deep wells. Seven electrically-operated pumps. Current for pumps supplied by 175-kw. generator driven by 350-hp. gasoline engine. There are 2 elevated tanks of 70,000- and 150,000-gal. capacity.		21 hr. 15 min.	Not less than one-half normal elevated storage available during storm.

tanks of 70,000- and 150,000-gal. capacity.

Location	*Source of Supply and Power*	*Damage to Services*	*Current Off*	*Remarks*
Stone Harbor	Electrically- and gasoline-driven air compressors and pumps.	Seven house services broken.	27 hr. 15 min.	Water in 100-ft. standpipe did not fall below the 50-ft. level.
Surf City	Two electrically-driven pumps with one gasoline-driven reciprocating pump in reserve.	Four 2-in. and 20–25 ¾-in. services broken.	51 hr. 15 min.	When water in 115-ft. standpipe dropped to 20 ft. valve was closed reserving that water for use in case of fire.
Tuckerton	10-in. well or from Lake Pohatcong either by electric pumps or by water power. 50,000-gal. elevated tank.		48 hr.	Water wheel used during 48 hr. that current was off. No services, mains or hydrants broken and normal pressures maintained.
Ventnor City	Two pumping stations. Main station has two 3-mil.gal. and two 1.5-mil.gal. steam pumps and one 4-mil.gal. electrically-driven centrifugal pump. Wells operated by air lift and discharge into 600,000-gal. concrete reservoir. 300,000-gal. elevated tank. Surrey Ave. Station has one 0.72-mgd. deep well pump electrically driven.	Four hydrants and eight services broken.	19 hr. 45 min.	Pressure never fell below 30 lb.

Salt Water Encroachment in Southern Florida

By Garald G. Parker

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Presented on Nov. 13, 1944, at the Florida Section Meeting, St. Petersburg, Fla.

THE U.S. Geological Survey, in cooperation with Dade County and the cities of Miami, Miami Beach and Coral Gables, and the Florida Geological Survey, began an intensive investigation of the ground water of southeastern Florida in the fall of 1939. This investigation was occasioned by the appearance of salty water in the Miami well field, near the Miami Canal, about 6½ mi. inland from Biscayne Bay.

One of the most important problems to be solved during the investigation was that dealing with the source and movement of salt water that had contaminated the well field. Several approaches were made to the problem, by means of which it was determined that the salty water had not come from bodies of connate water, nor directly from the bay at depth in the aquifer, but had found its ingress up the Miami Canal chiefly during times of low flow in the canal and high tides in the bay, and had moved laterally from the canal directly into the well field following the gradient of the shallow cone of depression that surrounds the well field.

It is the purpose of the author to discuss the occurrence and principles of salt water encroachment as exemplified by conditions studied in the Miami investigation. These principles, it is believed, are generally applicable to other coastal areas of Florida, even though the local geology is somewhat different. This paper is a record of further studies of the general subject matter first recorded in this JOURNAL by Cross and Love (1). Readers who have a copy of the April 1942 issue should refer to this article.

Physical Features of the Miami Area

Miami is on the Atlantic Coastal Ridge—an irregular, low, sand-mantled limestone strip averaging about 6 mi. wide lying between the marshy Everglades to the west and Biscayne Bay to the east (Fig. 1). Biscayne Bay is a very shallow body of water separating the Coastal Ridge from the off-shore bar on which Miami Beach is built. In several places uncontrolled drainage canals cut through the Ridge to the Everglades; likewise cutting through the Coastal Ridge between Miami and Fort Lauderdale are several old discharge channels now filled with sand to a depth of about 100 ft. The Coastal Ridge is scarcely noticeable as such. It rises almost imperceptibly from the Everglades and falls gently to the bay. Its altitudes average, perhaps, about 8 ft. above mean sea level. Highest elevations are about 25 ft. above mean sea level and are near Cocoplum Plaza in Coral Gables on the western shore of Biscayne Bay.

Along the east side of the Coastal Ridge at Silver Bluff in Miami a low Pleistocene sea cliff having its base 5 ft. above mean sea level is developed in the Miami oölite. At the base of the cliff is a wave-cut bench that slopes gently out under Biscayne Bay. The bench extends north and south from Silver Bluff, and can be traced for many miles in Dade and southern Broward Counties where U.S. Highway No. 1 follows along or near the old shore line (2). This feature is well preserved where cut in limestone but has been destroyed where sand or other unconsolidated materials form the old shore.

Climate

Miami has a semi-tropical climate with an average annual rainfall of about 59 in. There are usually distinct wet and dry seasons each year that last, respectively, from June through October and from November through May. The prevailing winds are from the southeast; and transpiration and evaporation are very high the year around.

Geology

The structure and stratigraphy of the area are illustrated in Figs. 2 and 3. Figure 2 is a generalized geologic cross-section extending in a north northwest-south southeast direction from the vicinity of Ocala to Florida City, a distance of about 300 mi. Figure 3 is a generalized geologic cross-section about 29 mi. long extending in an east-west direction along the Tamiami Trail (U.S. Highway No. 94).

The principal geologic structure is the Ocala anticline, an elongated breached dome that reaches the surface in north central Florida where the Ocala limestone crops out. In part of the area the Ocala limestone is as much as 150 ft. above sea level. This anticline trends northwest-southeast and plunges to the southeast in southern Florida. Younger formations lie upon the Ocala limestone, the eroded and solution-riddled formation of Eocene age which forms the exposed surface of the structure, and dip gently seaward in all directions. Under the Ocala limestone are thousands of feet of calcareous, dolomitic, anhydritic, gypsiferous and halitic sediments of Eocene and Cretaceous ages that extend to at least 13,512 ft., the depth penetrated by an oil exploratory well near Sunniland, Florida (3). The basement complex of metamorphic and igneous rocks, which is supposed to underlie this part of the state, was not penetrated.

Overlying the Ocala are the Suwannee limestone (Oligocene) and the Tampa limestone (Miocene), both of which contain mineralized artesian water in southeastern Florida. Along with the Ocala they act as an artesian unit in which water is confined under sufficient pressure to cause it to rise above the land surface in wells wherever the elevation is less than 50 ft. above mean sea level (except in the Florida Keys where the artesian head is approximately at sea level).

The Hawthorn formation of Miocene age comprises 400 to 500 ft. of relatively impermeable materials, chiefly green sands and greenish colored silty, clayey or very fine sandy marls, with a few shell marl and thin limestone beds. It overlies the Tampa and older limestones and prevents or retards upward percolation of the artesian water from these limestones.

Overlying the Hawthorn, in southeastern Florida, are two contemporaneous formations of Pliocene age, the Caloosahatchee and the Tamiami for-

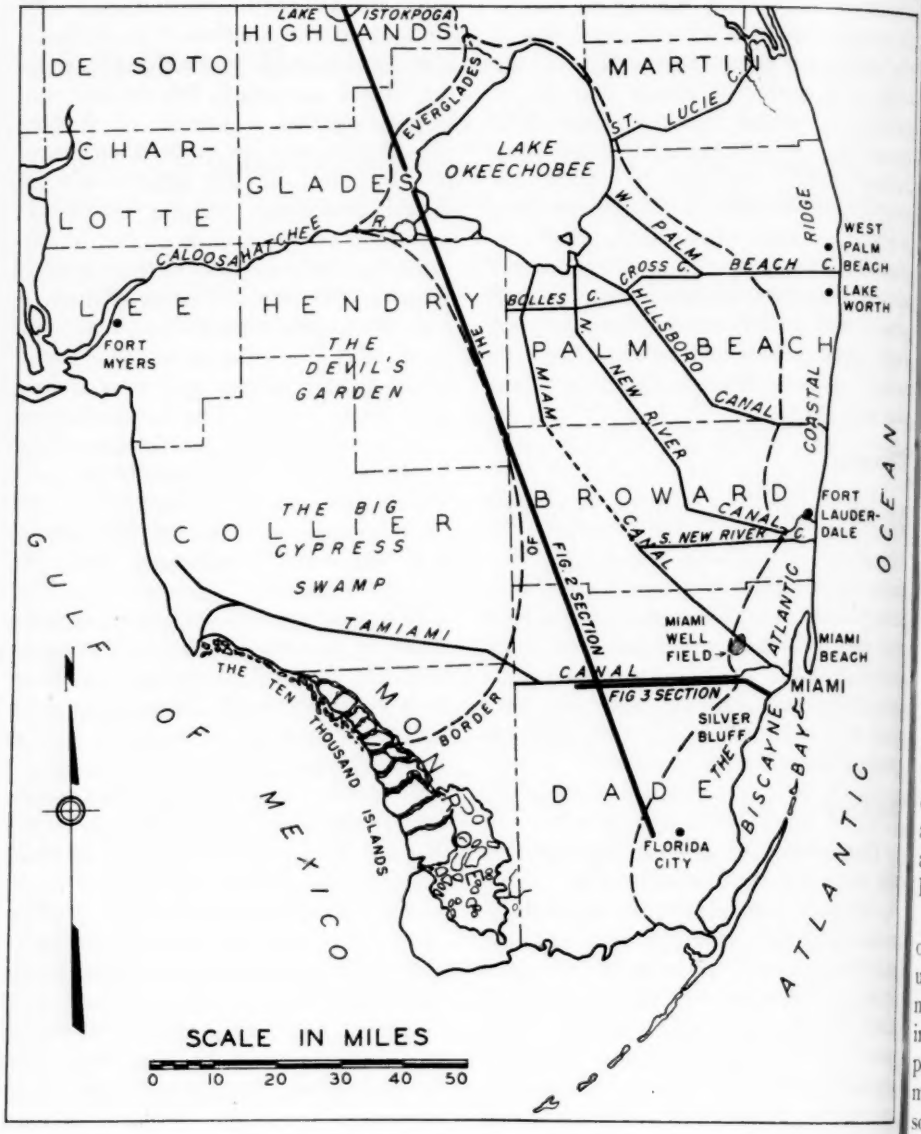

FIG. 1. Map of Southern Florida

mations. The Caloosahatchee formation is a shallow ocean bottom deposit of low permeability that consists largely of clayey, silty and sandy shell marls. The Tamiami formation is composed of marine sandy limestone, calcareous sandstone and beds and pockets of quartz sand; it is one of the most permeable formations ever investigated by the U.S.G.S., ranking with clean, well-sorted gravel in its ability to transmit water. The permeability is due to the great development of a network of solution channels and caverns in the calcareous rocks of the formation. The formation is wedge-shaped in cross-section, thin toward the interior and thick toward the coast. It interfingers with the Caloosahatchee formation under the Everglades in the latitude of Fort Lauderdale.

Overlying the Tamiami is the Miami oölite, of late Pleistocene age, cross-bedded to massive oölitic limestone. It is highly permeable in a vertical direction due to the large number of solution holes which penetrate it, but it has a much lower permeability in a horizontal direction. Mantling the Miami oölite, and filling solution holes in it and the underlying Tamiami formation, are permeable quartz sands of the Pamlico sand (late Pleistocene).

This brief description of the geology of the area is given as a basis for an understanding of the occurrence and movement of ground waters described in the following sections. A more complete account of the historical development of the late Cenozoic geology of southern Florida is given in a report by Parker and Cooke (2).

Ground Water

General

In southern Florida, water in wells which penetrate the artesian aquifers below the Hawthorn formation will rise above the land surface. The water is hard, saline, sulfurous and, in southeastern Florida, is generally so corrosive that it is unfit for use. Used as cooling water in condensers it corrodes the condenser tubes and over a period of time is more expensive to use than treated water from shallow wells. The largest yields of artesian water in southeastern Florida are from wells that range in depth from 800 to 1,200 ft., and in southwestern Florida from wells with depths of from 400 to 1,000 ft. The artesian water in southwestern Florida is hard and sulfurous but generally not too saline for many uses. Indeed, it is commonly used as drinking water and for irrigation, especially in rural areas.

Very little water is obtainable from the Hawthorn formation itself, although limited quantities under low artesian pressure occur in the more permeable beds. The quality is generally very poor.

The potable ground water supplies in southeastern Florida are obtained from the formations that overlie the Hawthorn; these are the Tamiami and Caloosahatchee formations of Pliocene age, and the Miami oölite and Key Largo limestone of Pleistocene age. The Tamiami formation is the most productive of these aquifers. It underlies the Atlantic Coastal Ridge as far north as Delray, and is the source of most of the water supplies in southeastern Florida.

Although the Miami oölite and part of the coralline Key Largo limestone are permeable, the largest supplies are obtainable from the underlying Tamiami formation. The Caloosahatchee formation is important as an aquifer principally along the Atlantic Coastal Ridge north of Delray.

TABLE 1

Analyses of Water Samples from Test Wells in Southeastern Florida
Analyses by U.S. Geological Survey
(ppm.)

Well No.	Location	Date Sample Collected	Depth Sample Collected *ft.*	Color	Dissolved Solids	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na +K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Total Hardness as $CaCO_3$	Analyst	Remarks
G182	The Parkway south of Morningside Drive, Miami Springs, Dade Co.	8–29–40	94	—	643	123	13	101	229	57	236	360	G. J. Petretic J. E. Mykytka	Bailer sample. Ground water contaminated by encroaching salt water.
G184	7 mi. west of Florida Highway No. 149 at west end of Hollywood Blvd., Broward Co.	10–16–40	92	25	266	68	10	22	243	15	31	211	W. W. Brannock J. E. Mykytka	Bailer sample. Color may be low.
G185	Miami Gardens Drive and Douglas Road, Dade Co.	10–23–40	99	75	323	102	8.6	12	322	19	23	290	W. W. Brannock J. E. Mykytka	After pumping 50 min. at 200 gpm.
G186	Northwest 17th Ave. and 55th Terrace, Miami, Dade Co.	11– 4–40	101	20	282	94	5.5	9.4	291	7.8	22	257	W. W. Brannock J. E. Mykytka	After pumping 45 min. at 100 gpm.
G187	Pennsuco, Dade Co.	11–15–40	91	50	300	90	9.9	15	310	5.6	27	265	W. W. Brannock J. E. Mykytka	After pumping 30 min. at 220 gpm.
G188	Krome Road and Tamiami Trail, Dade Co.	11–20–40	44	80	298	90	7.5	19	320	1.0	23	255	W. W. Brannock J. E. Mykytka	After pumping 30 min. at 220 gpm.
G198	0.2 mi. south of Coral Way and 0.7 mi. west of Ludlum Rd., Coral Gables, Dade Co.	4–21–41	102	—	324	101	15	5.8	345	5.3	27	314	H. A. Swenson J. E. Mykytka	After pumping 15 min. at 10 gpm.
G207	0.1 mi. north of Lucille Drive and 0.25 mi. east of Redland Rd., southwest of Florida City, Dade Co.	1–29–41	55	—	197	70	2.2	5.3	215	2.0	12	184	H. A. Swenson J. E. Mykytka	After pumping 15 min. at 110 gpm.
G217	160 yd. east of U.S. Highway No. 1 and 1.5 mi. north of Campbell Drive, Redlands Project, U.S.D.A. Migrant Labor Camp, Dade Co.	8–26–41	88	—	201	67	3.5	7.2	212	8.2	10	182	H. A. Swenson J. E. Mykytka	Jetted sample.

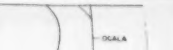

FIG. Cross- Florid

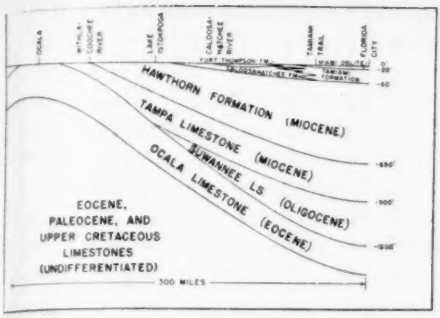

FIG. 2. Generalized NNW–SSE Geologic Cross-Section From Vicinity of Ocala to Florida City—Greatly Foreshortened

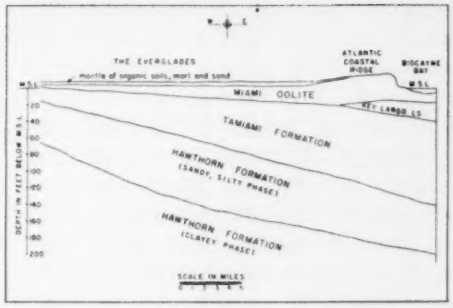

FIG. 3. Geologic Cross-Section Along Tamiami Trail (U.S. Highway 94), Dade County

Quality of Ground Water

The ground water is similar in quality throughout the Tamiami and overlying formations except where contaminated by salt water. The hardness ranges from 200 to 300 ppm. and averages about 250 ppm. Normal chloride concentration is from 15 to 30 ppm. All the ground water is colored with organic matter, but in varying degree from place to place. The color is derived principally from peat, muck and other organic matter. Ground water in the Coastal Ridge and north and south of Miami has the same general chemical make-up as that in the Miami area except that it generally is softer and has a lower mineral content. (See Table 1.)

In the Everglades west and northwest of Miami the highly permeable aquifer (Tamiami formation, principally) pinches out, and the quality of the ground water generally becomes poorer with increasing distance from Miami. This change in quality is due to several factors: (1) low permeability of the rocks underlying the middle and upper Everglades; (2) low gradients that cannot force ground water to move readily in these rocks of low permeability; and (3) there has not been enough time since the ocean last covered this area in the late Pleistocene (Wisconsin glacial stage) for the rain water to flush out the sea water completely. However, the quality of this water has been greatly modified, partly by dilution with fresh rain water and partly by chemical reactions—mainly of the base exchange variety—with the surrounding rocks and organic matter. There are extensive areas in the Everglades underlain by highly mineralized bodies of ground water above the Hawthorn formation.

Salt Water Encroachment

General

The source of salt water contaminating the ground water in southern Florida may be the ocean or sea water that entered the water bearing formations prior to Recent time.

Most of the salt water contaminating the shallow ground water in the coastal areas is derived from the ocean, either through canals and natural waterways, or through lateral and/or vertical movement at depth in the aquifer. In the interior some of the shallow ground water is contaminated by residual sea water that gained access to the water-bearing formations during the high sea

TABLE 2

U.S.G.S. Analyses of Ground Water of Relatively High Mineralization, ppm.

Well No.	Location	Date Sample Collected	Depth *ft.*	Color	Dissolved Solids	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Total Hardness as $CaCO_3$	Analyst	Remarks
GS1	North New River Canal, 6 mi. north of 20-mi. Bend, Broward Co.	6– 4–42	55	—	949	168	31	165	669	7.8	248	547	H. A. Swenson J. E. Mykytka	Bailer sample.
GS2	North New River Canal, 3.5 mi. south of Bolles Canal, Palm Beach Co.	6– 9–42	50	—	1,044	197	78	107	924	12	195	812	H. A. Swenson J. E. Mykytka	Bailer sample.
GS3	South Shore Camp of U.S. Sugar Corp., Bean City, Palm Beach Co.	6–11–42	55	—	942	102	68	168	686	101	165	534	H. A. Swenson J. E. Mykytka	Bailer sample.
GS7	Florida Highway 25, 0.5 mi. west of Florida Highway 194, Palm Beach Co.	6–25–42	50	—	3,600	80	71	1,225	1,097	305	1,375	492	H. A. Swenson J. E. Mykytka	Bailer sample.
GS11	South side of Hillsboro Canal, 11 mi. west of Florida Highway 199, Palm Beach Co.	8– 5–42	50	70	7,210	218	166	2,299	836	716	3,400	1,226	H. A. Swenson	After pumping 20 min. at 75 gpm.
GS14	Two Palms Island, 15 mi. north of 40-mi. Bend in Tamiami Trail, Dade Co.	9–26–42	51	10	859	108	18	205	508	49	228	344	S. K. Love H. A. Swenson	After pumping 20 min. at 150 gpm.
GS17	0.2 mi. east of Kissimmee River and 0.5 mi. north of Lake Okeechobee on Florida Highway 29, Okeechobee Co.	7–17–43	49	38	1,140	184	31	225	730	5	335	586	M. B. Thomas	Bailer sample.
GS18	0.2 mi. southwest of Indian Prairie Canal on Florida Highway 29, Glades Co.	7–22–43	75	45	1,041	103	40	241	528	129	268	422	M. B. Thomas	Bailer sample.
GS19	0.1 mi. northwest of Martin-Okeechobee County Line, Florida Highway 194, Okeechobee Co.	7–23–43	49	32	1,659	139	55	424	392	63	785	573	M. B. Thomas	Bailer sample.
GS23	10 mi. southeast of Indiantown, Florida Highway 29, Martin Co.	8–12–43	90	12	920	128	26	182	418	139	238	426	M. B. Thomas	Bailer sample.
GS24	3.5 mi. north of Canal Point, Florida Highway 143, Palm Beach Co.	8–14–43	43	310	4,030	232	95	1,222	1,780	254	1,350	970	M. B. Thomas	After pumping 25 min. at 215 gpm.
GS25	1.8 mi. south of Pahokee, Florida Highway 143, Palm Beach Co.	8–18–43	45	250	4,390	204	103	1,357	1,155	267	1,885	932	M. B. Thomas	After pumping 30 min. at 150 gpm.
GS26	North end Kraemer Island, 8 mi. northwest of Belle Glade, Palm Beach Co.	8–21–43	42	240	2,780	176	180	646	1,305	221	910	1,179	M. B. Thomas	After pumping 30 min. at 145 gpm.
GS27	1.7 mi. west of Lake Harbor and 4.5 mi. east Hendry County Line, Palm Beach Co.	8–25–43	56	25	3,500	165	98	1,013	882	605	1,180	815	M. B. Thomas	Bailer sample.
GS28	Moore Haven, Florida Highway 67 and Caloosahatchee Canal, Glades Co.	8–28–43	47	90	852	144	12	175	468	10	280	409	M. B. Thomas	Bailer sample.

levels of the interglacial stages of the Pleistocene when the seas covered southern Florida to depths as great as 250 ft. (4). Most of the sea water that invaded the formations during the Pleistocene has long since been flushed from the rocks of southern Florida, especially from the rocks underlying the Atlantic Coastal Ridge. During glacial stages, when sea level fell as much as 300 ft. below the present level, and possibly much more (5), these formations, which are highly permeable down to the Hawthorn formation, were flushed of their saline water by fresh ground water, and even the more permeable parts of the Hawthorn were largely cleared of salt water. However, the less permeable parts of the formations, especially in the Lake Okeechobee-Everglades depression, were not entirely flushed. These highly mineralized waters are generally trapped in the least permeable sediments, or in lenticular or shoestring deposits of more permeable materials that are enclosed by relatively impermeable clays or clayey marls. Their original chemical composition has been changed by dilution and by base exchange (6) with enclosing rocks and with organic materials. Table 2 lists analyses of some of these highly mineralized ground waters.

Contamination by Canals

Canals were dug in southern Florida to drain the swamp lands and thus make available for farming the millions of acres of lands that were perennially too wet. The program started near the close of the last century, received impetus during the period 1910–1918 when most of the major Everglades canals were dug and then received another boost about 1925–1927 during boom-time developments.

Prior to the drainage program water levels had been high not only in the Everglades but also under the Atlantic Coastal Ridge down to the very shore line. In the Everglades the land surface was usually below the water surface; and along the Atlantic Coastal Ridge, in the vicinity of Miami, the water table was so high that springs flowed in many places along the shore line at elevations up to 5 ft. above mean sea level. Thus, before drainage began, salt water from the ocean was held in check by the high head of fresh water on the land, and salt water did not encroach because of the high discharge of fresh water.

As a consequence of the cutting of the canals the water table was lowered, not only in the Everglades where the drop was readily apparent, but also under the rock surface of the Atlantic Coastal Ridge where it was not so easily noticed. The first well field of the city of Miami, which was located about 1½ mi. west of Biscayne Bay near the Miami River, became salted, and was, therefore, abandoned in 1925. Not long thereafter the springs that had formerly flowed perennially along the western shore of Biscayne Bay ceased flowing. This caused some temporary alarm, but no enduring concern —there was still plenty of fresh water.

The lowered water table had, however, decreased the amount of water available to discharge seaward through the canals during drought times, and when such times occurred salt water penetrated farther and farther inland up the canals. This penetration was not generally noted until April 1939, when the Miami Canal was first found to contain salty water as much as 10 mi. upstream from its mouth. Soon thereafter, wells in the new city well field in Miami Springs and Hialeah be-

came salted, and it was realized that the problem was critical.

Salt water is heavier and denser than fresh water; so much so that a column of salt water 40 ft. high weighs the same as a column of fresh water 41 ft. high. The specific gravity of fresh water is very nearly 1.000 and that for ocean water is about 1.025.

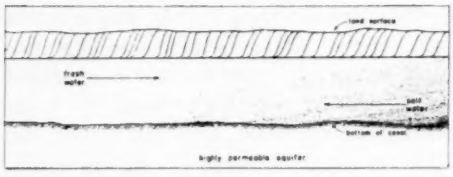

FIG. 4. Cross-Section Showing Salt Water-Fresh Water Relationship in a Tidal Canal—Length of the Salt Water Wedge Variable up to Several Miles

As a result of this difference in specific gravity and in density, when salt and fresh water meet they tend to remain separate, with a comparatively narrow zone of diffusion between the two, unless there is enough agitation to cause mixing.

Thus, when salt water moves upstream in a canal or river it creeps along the bottom. In an upstream-downstream vertical section it moves as an elongated wedge whose thin edge is directed upstream and whose length varies up to several miles. Over this salt water wedge fresh water may, and usually does, continue to flow seaward. (See Fig. 4.)

Under some conditions in the Miami area the direction of flow in the lower courses of the canals may be entirely reversed by high tides, and during periods of from two to four hours out of each tidal cycle no fresh water flows in a seaward direction.

The amount of salt water gaining access to a canal that empties into ocean water, and the shape and dimensions of the encroaching wedge of salt water are dependent upon many factors, such as the depth and width of the canal; its relative freedom from channel-clogging weeds; the stages of the tide and canal; the volume of fresh water flowing seaward; the direction, velocity and continuity of winds; and the presence or absence of control structures in the canal.

The amount of salt water that escapes from the canal into the adjacent rocks is dependent upon several factors. Among these are: the capacity of the rocks through which the canal is cut to transmit water; the presence or absence of a layer of silt which, if present, may act as a relatively impermeable seal which will prevent free movement of water from the canal to the adjacent rocks; the height of the water table adjacent to the canal compared to the height of the water surface in the canal.

In southeastern Florida the rocks through which the canals are cut in the the Atlantic Coastal Ridge are of very high permeability and transmit water very readily. The amount of silting in the canals is variable both in time and place. In some parts of the canals the bottom appears to be well sealed by a deposit of calcareous mud, organic material and very fine sand. In other parts free exchange of canal and ground water takes place through the bottom. These conditions lead to salting of some areas along the canals, whereas other areas remain unsalted or receive only a small amount of salty water. Complicating natural conditions is the factor of pumpage. Where the effects of the draft on ground water extend to the canal, movement of canal water into the water-bearing formations may be increased.

The following generalizations on salt water contamination are based on ground water studies made along that stretch of the Miami Canal between Northwest 36th and 54th Streets, a portion of which is usually reached by the cone of depression formed in the water table by draft from the Miami well field. Figure 5, a map of the area, shows a typical cone of depression in the water table.

Figure 6 represents a geologic cross-section of this same area showing ground water conditions as they were before salt water made its first appearance in the canal in 1939.

When salty water, in large quantities, first reached this stretch of the canal, wherever the canal bottom was not silted too heavily, it penetrated downward toward the bottom of the aquifer. In doing so it constantly encountered fresh water, and was as constantly diluted, until it finally reached the top of the relatively impermeable Hawthorn formation. With salt water remaining long enough in the canal, all fresh water directly under it disappeared (Fig. 7) and saline water of a lessening degree of chloride concentration (as the bottom was approached) completely occupied the former fresh water zone. The pumping of an average of 30 mgd. in the nearby Miami well field caused a general southward movement of the salted body of water, as illustrated in Figs. 7, 8 and 9.

At the close of the drought period in 1939, the fresh water discharge increased and salty water in the canal was swept downstream beyond the new zone of contamination. But the salty water in the ground under the canal was not disposed of so quickly. It continued to sink toward the bottom of the aquifer and to create a salt water mound on top of the Hawthorn formation (Fig. 8). By dilution with the overlying fresh water from the canal and the surrounding fresh water on all sides as it was drawn toward the well field, the mound of salty water finally became entirely isolated from its original source and the water of greatest chloride content came to be at the bottom of the aquifer.

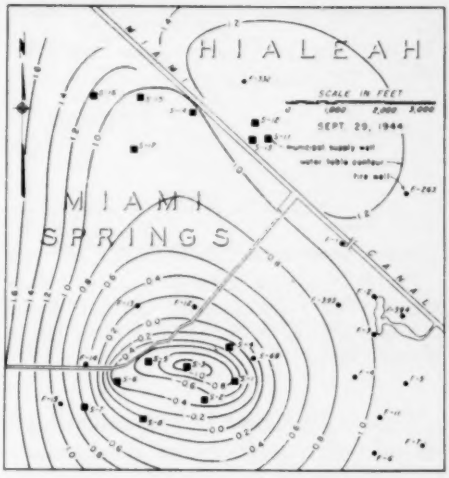

FIG. 5. Map of Miami Well Field Area Showing Contours Representing the Water Table and a Typical Cone of Depression—Contour Interval 0.2 ft.—City Supply Wells Are Shown as Heavy Squares

Figure 9 shows a still later stage in the history of this salt water encroachment. The salty water is continually but slowly being diluted by fresh ground water, and also is being removed by pumping from the well field. If no further contamination occurs through the canal the final stage will be reached with a return to original conditions as shown in Fig. 6.

Encroachment of salt water also takes place in areas along canals that contain salt water continuously. In such areas, however, the manner of salt water encroachment is the same as that which occurs at depth in the aquifer directly from the ocean.

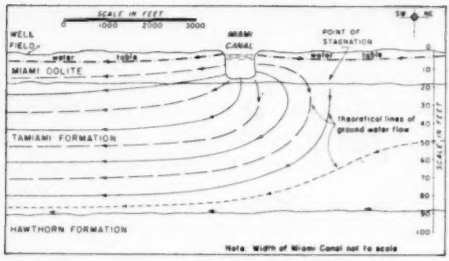

FIG 6. Geologic Cross-Section Near Miami Well Field Showing Ground Water Conditions Prior to Salt Water Incursion in Miami Canal

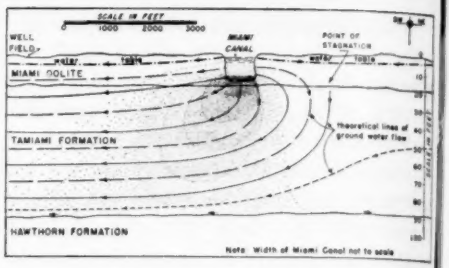

FIG. 7. Geologic Cross-Section Near Miami Well Field Showing Salt Water in Miami Canal and Probable Method of Contamination of Aquifer

Figure 10 shows how residual bodies of salty water may contaminate fresh water of an overlying canal or other stream. The illustration represents a section of the North New River Canal in its upper reach, south of the Bolles Canal. At a time when the North New River Canal is effluent, that is, its water level is lower than the adjacent water table and the canal is fed by the ground water, salty water from the Fort Thompson and Caloosahatchee formations leaks upward into the canal. Water from the land surface and from Lake Okeechobee is very low in dissolved minerals and the amount of chloride in the water, which may be used as a criterion of contamination, is generally less than 20 ppm. However, under effluent conditions it is not unusual for the canal water to contain as much as several hundred parts per million of chloride. During times when the canal is influent it may, and often does, carry water of less than 10 ppm. chloride.

Salt Water Encroachment at Depth in the Aquifer

As this subject was rather completely covered in a previous paper (7), only the principal elements involved will be discussed herein.

Because of its lower specific gravity and density, fresh water will "float" on a body of salt water much as an iceberg floats on the ocean (8). Where conditions of equilibrium between fresh and salt water have been reached, there is a definite relationship between the height of fresh water above mean sea level and the depth to salt water. Studies dealing with this relationship were made independently by B. Ghyben and A. Herzberg in Europe shortly before 1900. John S. Brown (9) reviewed their work and applied it to his work in Connecticut.

Out of the investigations of these two Europeans has grown the Ghyben-Herzberg theory. These studies show that in the coastal areas investigated the depth to salt water is largely a function of the height of the water table above sea level and the difference in the specific gravity of the fresh water and the salt water. This relation is expressed by the simple formula: $h = t/g-1$, in which h is the depth of the fresh water below sea level, t is the height of the fresh water surface above sea level, and g is the specific gravity of the salt water. The specific gravity of sea water differs somewhat from one locality to another and may also be different at different depths. If the spe-

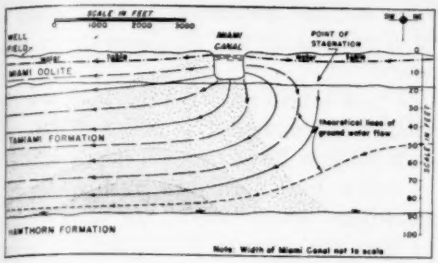

FIG. 8. Geologic Cross-Section Near Miami Well Field Showing Conditions Several Months Subsequent to Salt Water Encroachment in Aquifer

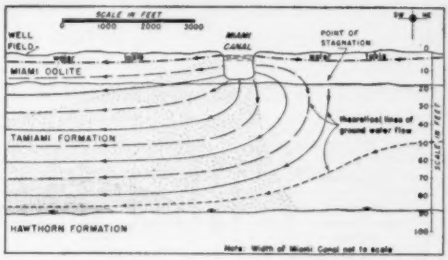

FIG. 9. Geologic Cross-Section Near Miami Well Field Showing Late Stage in Salt Water Encroachment in Aquifer

cific gravity of sea water is about 1.025 and the water table or hydrostatic head is 1 ft. above sea level, the depth to the contact between salt and fresh water is according to the formula about 40 ft. below sea level. In other words, for each foot of fresh water above sea level, the fresh water extends 40 ft. below sea level.

Investigations by the U.S.G.S. in the Miami area indicate (7) that the Ghyben-Herzberg theory is applicable, in general, to the shallow water-bearing formations along the coast of southeastern Florida, and also that it appears to apply, in general, to other coastal areas of the state.

In the Miami area the long established equilibrium between salt and fresh water (see Fig. 11, 1910 contact) was upset by the lowering of the water table, and a new equilibrium is now in process of being reached. The 1:40 ratio is applicable in the contaminated zone only where equilibrium has been reached, and then applies on the basis of an average water table height for the preceding few months.

The height of the water table taken at any time or place within the contaminated zone may not apply because the water table then and there may be higher or lower than the average for the past few months. It had been previously pointed out by Wentworth (10) that an adjustment of the equilibrium between salt and fresh water to change in water table lags far behind the time of water level change because salt water can only move in as fast as fresh water is removed at depth in the aquifer. The Miami investigation confirms this. Thus the Ghyben-Herzberg theory cannot yet be applied at all distances back from the shore in southeastern Florida because not enough time has elapsed since the original balance was upset for the final balance to be reached. Also, the ratio will not apply to conditions some distance from the contaminated zone even after equilibrium has been reached, if the fresh water head is sufficient to hold the salt water contact at a depth greater than the depth to the bottom of the permeable beds.

In Fig. 11 the section is normal to the shore at Silver Bluff, Miami, and shows approximately the successive positions of the salt water-fresh water contact from 1910 to 1944. The section is diagrammatic and does not necessarily represent conditions exactly as they were for the times shown. No detailed surveys of the salt water-fresh water relationship were made before 1939, and the illustrations show-

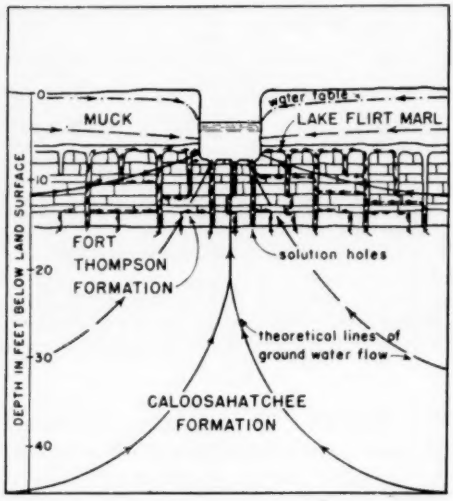

FIG. 10. Geologic Cross-Section Under North New River Canal Showing Canal in Effluent Condition and Residual Salty Ground Water Contaminating Canal Water

ing conditions prior to 1939 are based on reports by persons who were living in Miami before that time, and upon the analysis of samples of water from a few wells in 1928. The years in which certain wells in the area first became noticeably salty are recalled by many owners. Thus, by checking and plotting reported conditions and by assuming others, the salt water-fresh water contacts for 1910, 1918 and 1928 have been worked out. The contacts for 1942 and 1944 are based upon actual ground water studies. Even though the conditions as illustrated may not be absolutely accurate for the times given, they show the general conditions, and represent diagrammatically the manner in which salt water encroaches at depth in the aquifer.

Figure 11, line 1910, shows the contact as it is assumed to have been in 1910 before the average water table had been materially lowered. At many places along the base of the old Pleistocene sea cliff perennial springs flowed at elevations up to 5 ft. above mean sea level.

There is also reported the former existence in Biscayne Bay of a well driven to a shallow but unknown depth which is said to have furnished fresh water to boatmen. How "fresh" the water was is open to question, but at least it was potable, thus indicating that salt water was not everywhere present under the bay as it is now. The marly bottom of the bay may have acted as an impermeable layer and thus helped keep the overlying salt water in the bay from seeping into the underlying fresh water; the principal factor, however, was the relatively high head of fresh water at the shore line.

Prior to the digging of drainage canals, a rather stable equilibrium had been reached between fresh water and salt water at depth in the aquifer. Allowing for an average of 5 ft. of fresh water above mean sea level very near the shore, the salt water contact would have been about 200 ft. below sea level. With the large fresh water discharge and fresh water head at that time, the salt water-fresh water contact may have been about as illustrated in Fig. 11, line 1910, and no salt water would have been present in the aquifer inland from the face of the cliff.

Figure 11, line 1918, shows the contact as it may have been about 1918. The Miami Canal had been draining both the back country and the Atlantic Coastal Ridge since 1910, and had materially lowered the water level. As a result, several of the higher springs ceased to flow. With the lowering of the water table the salt water began migrating inland.

Figure 11, line 1928, shows the contact as it may have been about 1928. During the Florida boom, in the in-

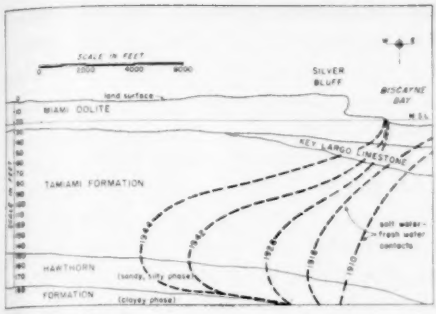

FIG. 11. Geologic Cross-Section of Silver Bluff, Miami, Showing Approximate Successive Positions of the Salt Water-Fresh Water Contact in the Interval 1910 to 1944

terval 1925–1927, there was a concerted effort to drain low-lying swamp lands that might be made into real-estate subdivisions, or sold for farming. As a result, numerous canals were dug in this area which further lowered the water table. Some of the higher of the springs along the shore ceased flowing a few years after the digging of the Miami Canal, but soon after the completion of the boom-time canals all springs ceased flowing—because the water table had permanently dropped below the orifices of these springs.

This lowered water table probably rejuvenated the inland rate of salt water movement. Wells that had formerly produced fresh water soon had to be abandoned.

The position of the contact in February 1942 is illustrated in Fig. 11, line 1942, which is based upon intensive studies made of fresh water-salt water relationships in the Silver Bluff area. The contact, however, is not a sharp line; rather, a diffusion zone about 60 ft. thick was found in which the chloride content ranged from 50 ppm. to 16,000 ppm. The 1,000-ppm. isochlor appeared to be the critical one with respect to the Ghyben-Herzberg theory and is the one used to illustrate the contact in these drawings. In the diffusion zone the distance between isochlors was found to be about as follows:

Isochlor Interval ppm.	*Distance Apart ft.*
50–100	17
100–200	14
200–1000	11
1000–6000	9
6000–16,000	9

Figure 11, line 1944, illustrates the position of the contact in October 1944, and indicates a great acceleration in the rate of salt water encroachment which is probably due to the exceedingly low average water table of 1943–1944. The salt front has advanced approximately 2,000 ft. in about 27 months, or an average of almost 890 ft. per year. Based on records ending in 1942, the inland movement had been estimated as 235 ft. per year (11). This accelerated rate may be only temporary; it may have occurred several times in the interval 1910–1942, but since observations were not being made, it could not have been detected. It is entirely likely that if several years of excessive rainfall should ensue, the

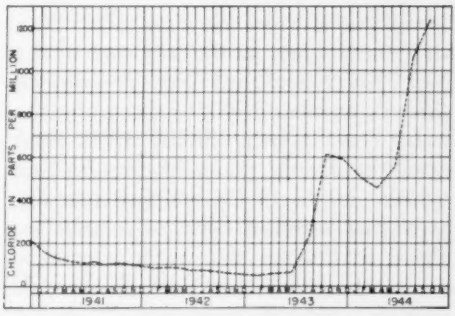

FIG. 12. Graph Showing Variation of Chloride in Well S330 at Florida Power & Light Co. Plant Near Fort Lauderdale, Broward County, 1940–1944

salt front would retreat somewhat. The Silver Bluff studies indicate that the inland encroachment of salt water at depth in the aquifer is not a steady, progressive movement, but is made haltingly by many separate advances interspersed with short retreats. However, there is no reason to suppose that the general inland movement of salt water will not continue, for in the Miami area there is not enough height of fresh water present above mean sea level to halt this movement until the salt front advances about 5 mi. further inland.

This same phenomenon of salt water encroachment is present at many other coastal cities in Florida, along both the Atlantic and Gulf coasts. A good example of one of these is in Fort Lauderdale, on the Atlantic Coastal Ridge about 24 mi. north of Miami. The New River cuts through the Atlantic Coastal Ridge and is connected to two major Everglades drainage canals, the North New River Canal and the South New River Canal. New River discharge is uncontrolled and salt water is free to move in and out of its lower course at least as far as the Davie Lock, which is about 9 mi. from the New River Inlet.

Although no intensive study has been made of this area, a periodic check on ground water in the low land of the New River area has been maintained since November 1940, by sampling the water from a well (S330) 35 ft. deep near the Dania plant of the Florida Power and Light Co. This particular area was selected because it was realized that when salt water encroachment occurred in the Fort Lauderdale area it would be first noticed in the aquifer along the New River. This well, because of its shallow depth, does not contain the greatest chloride content in the ground water of the area; if it were 100 ft. deep or more, it would doubtless show a much greater chloride concentration.

The chloride in well S330, when first sampled on Nov. 19, 1940, was 213 ppm. (See Fig. 12.) This shows considerable salt water contamination, for the chloride content of the water should have been about 20 ppm. to be normal. Doubtless it represents salt water remaining since 1939, at which time the Miami well field first became salted. In the interval from the date the well was first sampled to Jan. 28, 1943, the trend was for the chloride to decrease, although many minor changes occurred, and the chloride content finally decreased to 53 ppm. Then the effect of the drought became evident, and by Oct. 6, 1943, the chloride content increased to 615 ppm. The fall rains of 1943 gradually reduced this concentration (pushed the encroaching salt water wedge oceanward) to 458 ppm. by Apr. 4, 1944. Since that time the lowered water table and reduced flow in the New River has allowed salt incursion in the New River and North New River Canal as far west as the Davie Lock, and the chloride content of the ground water at the well has risen to 1,240 ppm. as of October 28. It is not known how far this tongue of salt water, moving at depth in the aquifer, has encroached laterally because no adequate studies have been made to determine it. Nor can it be foretold where this salt water encroachment will eventually come to an end in equilibrium with fresh water, for no studies of water table average heights are available. Information of this kind requires observations over a period of years.

Summary and Conclusions

The drainage program of southern Florida, aimed at reclamation of swamp lands, has upset the delicate balance that exists between salt water and fresh water in the aquifer along the coast, and has generally lowered the water table almost to sea level several miles inland from the ocean. This has resulted in the incursion of salt water in uncontrolled canals at times as far as 10 mi. from the source of the salt water, and has brought about local salting of ground water apart from the contamination that is taking place at depth in the aquifer. This latter form of salt water encroachment has moved landward in an uneven front, with lobes extending inland along some of the drainage canals for several miles. This movement is in direct consequence of a lowered water table, and is especially notable along the Atlantic Coastal Ridge, where the fresh water head is no longer sufficient to prevent encroachment of salt water. This movement will continue until a point is reached where the average annual height of the fresh water above mean sea level is sufficient to prevent further encroachment.

Salty water from remnants of bodies of sea water trapped in the formations during the Pleistocene is also a source of contamination. When canals passing above areas containing such saline bodies become effluent the upward movement of ground water through the bottom of the canal carries along with it some of this residual salt water. In some instances this raises the salinity of the canal water several hundred parts per million, and thus raises a serious problem for those who would depend upon the canal water for industrial use or for municipal supply. Examples of such canals are the North New River and Hillsboro.

The problems of salt water encroachment are not peculiar to southeastern Florida, where they have received the most study, but are common to other coastal areas of Florida where drainage programs or the over-development of ground water supplies have resulted in lowering the water table. As time goes on, unless remedial measures are applied to restore water levels to proper heights, more and more wells will become salted and irreparable damage will be done.

Acknowledgments

The author is grateful to his colleagues of the U.S.G.S. who have contributed in many ways to the advancement of the research in fresh water-salt water relationships made as a part of the southeastern Florida water resources investigation. The ground water data obtained by officials of the cities of Miami and Miami Beach during the spring and summer of 1939 were especially valuable in the interpretation of the conditions in the Miami area and the Everglades. The investigations of the Florida Geological Survey in co-operation with the U.S.G.S. gave the broad background essential in the interpretation. Among those whose personal efforts have been of inestimable value are O. E. Meinzer, V. T. Stringfield, W. P. Cross, Russell H. Brown, Nevin D. Hoy, L. K. Wenzel, S. Kenneth Love, C. E. Jacob, H. A. Swenson and John E. Mykytka.

References

1. Cross, William P. & Love, S. Kenneth. Ground Water in Southeastern Florida. Jour. A.W.W.A., **34**: 490 (1942).

2. PARKER, GARALD G. & COOKE, C. WYTHE. Late Cenozoic Geology of Southern Florida. Fla. Geol. Survey Bul. *No. 27* (1944), pp. 23–24.
3. CAMPBELL, ROBERT B. *Personal communication.* (Oct. 17, 1944.)
4. COOKE, C. WYTHE. Scenery of Florida. Fla. Geol. Survey Bul. *No. 17* (1939), pp. 33–35.
5. STEARNS, H. T. Pleistocene Shore Lines on the Islands of Oahu and Maui, Hawaii. Geol. Soc. Am. Bul., **46**: 1927 (1935).
6. LOVE, S. KENNETH. Cation Exchange in Ground Water Contaminated With Sea Water Near Miami, Florida. Trans. Am. Geophys. Union (1944).
7. BROWN, RUSSELL H. & PARKER, GARALD G. Salt Water Encroachment in Limestone at Silver Bluff, Miami, Florida. Econ. Geol. (*In press*).
8. BARKSDALE, H. C., SUNDSTROM, R. W. & BRUNSTEIN, M. S. Supplementary Report on the Ground Water Supplies of the Atlantic City Region. N.J. State Water Policy Com. Special Rpt. No. 6.
9. BROWN, JOHN S. A Study of Coastal Ground Water With Special Reference to Connecticut. U.S.G.S. Water Supply Paper 537 (1925).
10. WENTWORTH, C. K. The Specific Gravity of Sea Water and the Ghyben-Herzberg Ratio at Honolulu. Univ. of Hawaii Bul., **18**: 8 (1939).
11. PARKER, GARALD G., FERGUSON, GEORGE E. & LOVE, S. KENNETH. Interim Report on the Investigation of Water Resources in Southeastern Florida With Special Reference to the Miami Area in Dade County. Fla. Geol. Survey Rpt. of Investigation No. 4 (1944).

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Excerpts from A.W.W.A. Secretary's Memo of May 17, 1945, to Section Executives and Water Works Executives in Cities of 10,000 Population and Over

The Office of War Utilities, War Production Board, announced on May 12 a number of major changes in Utilities Order U-1, the basic wartime regulation for electric, gas and water utilities (WPB Release 7950).

Most significant change is the authorization to utilities to construct additions to their facilities involving up to $25,000 worth of materials without restriction from OWU.

Coincident with the relaxation on construction, OWU revoked all the supplementary orders to U-1. These are U-1-a, U-1-c, U-1-d, U-1-f, U-1-g and U-1-i.

Another major amendment to Order U-1 permits construction of plant improvements necessary to render service in accordance with "sound and economical operating standards." Previously, the order limited improvements to those necessary to maintain service at "minimum standards."

The priority rating of AA-1 for materials needed for maintenance and repair and as operating supplies is retained. Plant expansion involving materials costing between $10,000 and $25,000 is assigned an AA-3 rating. Plant expansion involving materials up to $10,000 retains the AA-1 rating of the old Order U-1 except that transmission and distribution materials and meters may be rated only AA-3.

Conservation of Ground Water in the Louisville Area, Kentucky

THE Louisville area, as the term is used in this report, is composed of the city of Louisville, in Jefferson County, Ky., and adjoining localities within a radius of several miles, including localities across the Ohio River in Indiana. Although the municipal water supply for Louisville is obtained from the Ohio River, for many years large quantities of water have been pumped from wells which draw from glacial outwash deposits that underlie the river valley.

A study of ground water conditions in the area was made in 1937 and 1938 by Woolsey M. Caye, Technical Engineer for the Commissioners of Sewerage of Louisville. The study was begun soon after the flood in the spring of 1937 with the purpose of determining the conditions causing basements to remain flooded and sewers to be overloaded after the flood had receded. Caye continued his study after 1937 because he could see that the ground water supply is limited and that heavy pumping by air-conditioning plants and industries was beginning to dewater the ground water reservoir. In 1939 he released a typewritten report entitled, "Ground Water—Well Report." As part of this investigation and previous work, fifteen observation wells were installed and periodical measurements of the water level elevations in them have since been made by the Sewerage Commission and by the Louisville Engineering Department.

Since the war began in 1939, pumpage from the water-bearing materials has been increased by about 65 per cent. As a result of the heavy pumpage the water table in the ground water reservoir has been lowered over the entire area, and several large cones of depression have been created in it around local areas of heavy pumping. The water levels in a number of wells have dropped below pump intakes, necessitating their lowering and, in some cases, deepening of the wells. Because the water-bearing materials are relatively thin, the yields of the wells have decreased as the water table has declined. In some localities a critical shortage of water has developed.

As the problem became more acute in the summer of 1943, the Geological Survey, U.S. Department of the Interior, was requested to make an investigation. Accordingly, in September 1943, an allotment of $7,500 from the emergency fund of the governor of Kentucky to the Geological Division of the Kentucky State Department of Mines and Minerals was matched with an equal amount by the U.S.G.S. to provide funds for the work until June 30, 1944. In December an appropriation of about $2,100 by the city of Louisville was matched by the U.S. G.S. to provide funds for the drilling of twelve test wells and for additional investigations. In February the U.S. G.S. allotted an additional $3,000 from special war funds.

Since the investigation began the geology of the area has been studied and the extent of the water-bearing materials mapped. An inventory has been made of about 660 wells, including all the large wells and others favorably located. A record of the amount of water pumped from all the wells during the past seven years has been compiled. All existing water level records have been studied and a program of periodically observing depths to water in about 130 selected observation wells has been initiated and continued. A number of wells have been drilled and others repaired for observational purposes. All existing data on tests of the specific capacities of wells have been studied. Several pumping and recharging tests have been made to determine the permeability and specific yield of the water-bearing materials. Chemical analyses and temperatures of water from a number of wells have been compiled, and further investigation of the quality of the water is in progress. A large program of exploratory test drilling and experiments with artificial recharge has been started.

The investigation has been under the general direction of O. E. Meinzer, Geologist in charge of the Division of Ground Water. Data have been furnished by the state geologist of Kentucky, the Commissioners of Sewerage of Louisville, the well drillers in the area, the WPB, individual well owners and many other interested persons.

Inventory of Wells

During the last three months of 1943 an inventory was made of all the wells in Louisville and its immediate vicinity and of representative wells in other parts of the river valley. The following information was tabulated wherever available: location, owner, driller, altitude, log, casing and screen data, water levels, pump data, pumping test data, pumpage records, temperature of water and chemical analyses of water. Except for a few confidential records, this information is available to the public in the files of the Geological Survey at Louisville.

Geology

General: The greater part of the Louisville area lies in the Ohio River Valley on unconsolidated glacial outwash and other river deposits of Pleistocene and Recent age. The valley was cut in limestone shale and tightly-cemented sandstone of Silurian, Devonian and Mississippian age, and is bounded on both sides by hills made of these rocks. The formations composed by these consolidated rocks are relatively uniform in structure and dip gently to the west.

The physiographic expression in the area is controlled largely by the characteristics of the formations immediately underlying the surface. The area is divided into four physiographic units: (1) the Ohio River Valley, which is directly underlain in most places by over 100 ft. of glacial outwash and Recent river deposits, which sediments in turn are underlain by the New Albany shale of Upper Devonian age and limestones of Devonian and Silurian age; (2) the Scottsburg Lowland, formed on the easily eroded and impervious New Albany shale; (3) the Muskatatuck Regional Slope, which is directly underlain by limestones of Silurian and Devonian age; and (4) the Norman Upland, underlain by tightly-cemented sandstone and shale

formations of the Borden group of Middle Mississippian age (Osage).

Nearly all of the large ground water supplies developed in the area are obtained from the glacial outwash deposits underlying the river valley. Only small and usually insufficient supplies are obtained from the formations beneath the glacial outwash and underlying the other three physiographic units. Results of a reconnaissance study of these consolidated formations indicate that they are not likely to be potential sources of large supplies of water of good quality.

Ohio River Valley: At Louisville the river valley is over 6 mi. wide. Northward it narrows rapidly so that near Harrod's Creek, about 8 mi. from Louisville, it is only 1¼ mi. wide. To the south of Louisville the valley gradually becomes narrower until at the south boundary of Jefferson County, approximately 19 mi. from Louisville, it is only about 1½ mi. wide. The Ohio River flows through the central part of the valley in the northern part of the area and along or near the western margin south from Louisville. The elevation of the land surface of the valley ranges from about 425 to about 475 ft. above mean sea level. Above the dam at Louisville the normal pool stage of the river is 420 ft. above mean sea level and below the dam the normal pool stage is 383 ft. Several small creeks and drainage ditches traverse the valley.

During the Pleistocene epoch the melt water from the Wisconsin ice sheet and from the Illinoian ice sheet greatly affected the size, depth and position of the Ohio River Valley. The Illinoian ice sheet extended southward nearly to Louisville. The valley was eroded to a maximum depth of nearly 130 ft. below the present land surface and then was filled with glacial outwash materials.

Figure 1 shows cross-sections of the elevations of the surface of the bedrock beneath the glacial outwash deposits which underlie Louisville and vicinity. The figure also indicates the saturated thickness of the deposits as of Feb. 1, 1944. A large well-preserved channel in the bedrock runs southwest under the area from the vicinity of the mouth of Beargrass Creek. The deepest part of this channel lies under Broadway at First Street, Dixie Highway at Wilson Avenue and Cane Run Road near the southwestern industrial area, and is 110 to 130 ft. below the present land surface. The channel is approximately 1 to 1½ mi. wide north of Broadway and becomes wider to the south. The average gradient of the channel is approximately 2 ft. to the mile. Tributary and minor channels and high parts of the rock surface under Louisville and vicinity are defined by the contours.

The bedrock rises abruptly from the channels beneath the valley and crops out at an altitude of approximately 460 ft. along the marginal areas. New Albany shale crops out along the present river channel from about the middle of New Albany, Ind., southward to about 1½ mi. south of the mouth of Falling Run. This shale was also encountered in wells and borings drilled in the southwestern industrial area. In the vicinity of the distilleries along Seventh Street Road and in the Fourth Street area the bedrock encountered in wells is probably the Louisville limestone of Silurian age. East of the mouth of Silver Creek, at the Falls of the Ohio, the Louisville dam is emplaced upon the Jeffersonville and Sel-

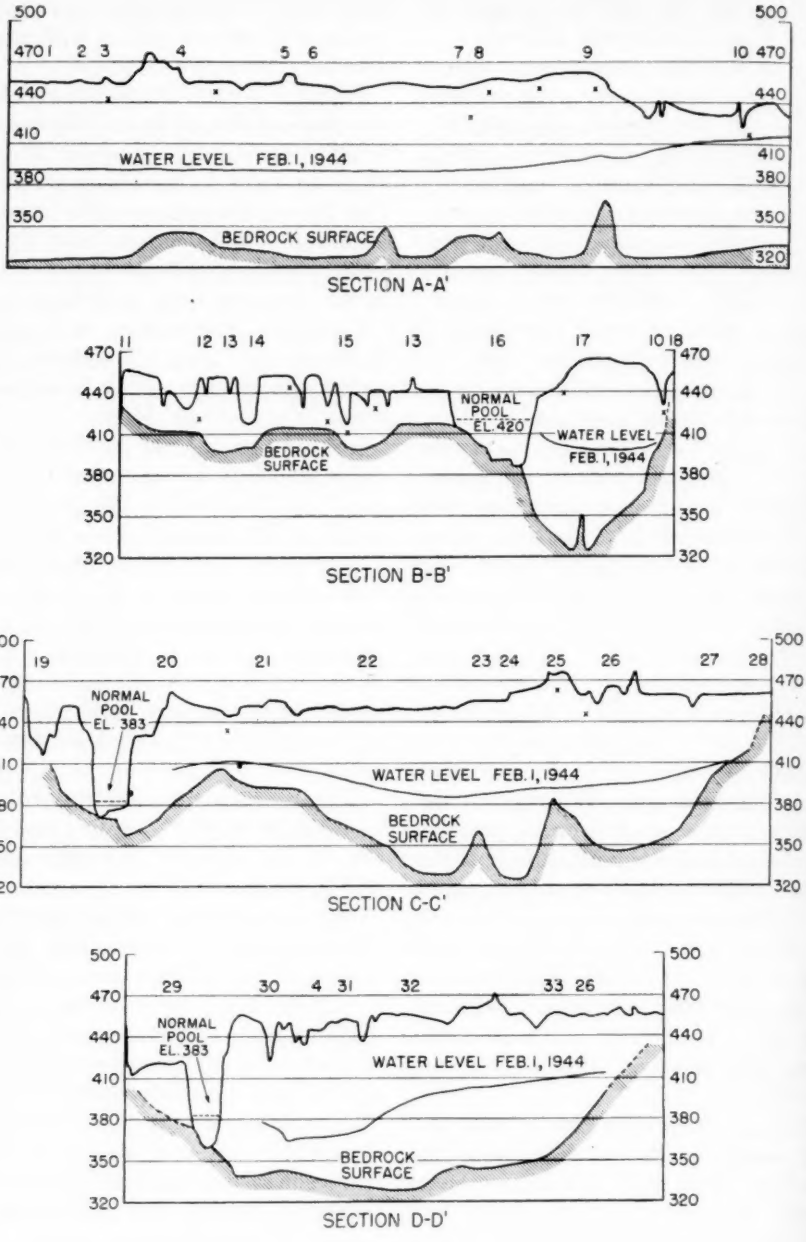

500
470 1 2 3 4 5 6 7 8 9 10 470
440
410
WATER LEVEL FEB. 1, 1944
380
350
BEDROCK SURFACE
320
SECTION A-A'
11 12 13 14 15 13 16 17 10 18
NORMAL POOL EL. 420
WATER LEVEL FEB. 1, 1944
BEDROCK SURFACE
SECTION B-B'
19 20 21 22 23 24 25 26 27 28
NORMAL POOL EL. 383
WATER LEVEL FEB. 1, 1944
BEDROCK SURFACE
SECTION C-C'
29 30 4 31 32 33 26
NORMAL POOL EL. 383
WATER LEVEL FEB. 1, 1944
BEDROCK SURFACE
SECTION D-D'
[SEE FIGURE 2]
X - CONTACT OF SURFICIAL AND GLACIAL OUTWASH MATERIALS
□ - CONTACT OF "BLUE CLAY" AND GLACIAL OUTWASH MATERIALS
HORIZONTAL SCALE 0 2000 4000 FEET

FIG. 1. Sections of the River Flood Plain, Louisville Area

KEY TO FIGURE 1

1. Illinois Central R.R.
2. Section D–D′
3. Cane Run Rd.
4. Algonquin Pkwy.
5. Dixie Highway & Magnolia Ave.
6. Section C–C′
7. 7th St.
8. Broadway at Fifth
9. Main St., Section B–B′
10. Beargrass Creek
11. Silver Creek
12. B & O R.R.
13. Penn. R.R.
14. Muskrat Creek
15. Pond Run
16. Municipal Bridge
17. Main St., Section A–A′
18. Barrett Ave. & Broadway
19. Falling Run Creek
20. Western Pkwy.
21. Market St.
22. Broadway & 28th St.
23. Dixie Highway & Dumesnil St.
24. Section A–A′
25. Hill St.
26. 7th St. Rd.
27. Wenner Ave.
28. L & N R.R.
29. River Rd.
30. Upper Paddy Run
31. Bells Lane
32. Section A–A′, Cane Run Rd.
33. Dixie Highway

lersburg limestone, of Middle Devonian age, and the rocks are exposed in the river bed at low water.

The limestones which compose part of the bedrock are slightly to moderately cavernous and moderately fractured. Only a limited number of producing wells have been successfully developed in these rocks, although numerous attempts have been made.

The Pleistocene glacial outwash sand and gravel overlying the bedrock in general vary inversely in thickness with the elevation of the bedrock surface, the thickness ranging from a featheredge in the marginal areas of the valley to over 125 ft. in the main channel in the bedrock. Examination of over 100 logs of wells and borings drilled in the area show that the outwash deposits are principally gravel and coarse-, medium- and fine-grained sand. Usually the gravel and sand are mixed, with gravel or coarse sand predominating, and make up interbedded lenses of different mixtures which vary in thickness from 5 to 20 ft. Occasionally lenses of well-sorted medium- or fine-grained sand occur. Well-sorted lenses of gravel are extremely rare. The lenses contain varying small quantities of finer material but are not clay- or silt-bound. Clay and silt lenses are seldom present, and when present are thin. The gravel varies from granule to cobble size, and the particles are well rounded and worn. Occasional boulders encountered by well drillers were probably rafted down the valley with fragments of ice from the melting ice sheet. Quartzitic, granitic and limestone particles predominate in gravels, whereas the sand is nearly all quartz with infrequent heavy mineral and limestone particles.

A dense, gummy, blue clay is encountered in wells in the northern part of Louisville and in Jeffersonville and New Albany. The clay varies in thickness from 1 to 30 ft. and is thicker in the northwestern part of Louisville than in the northeastern and eastern parts. It overlies glacial outwash gravels in the northeastern part of Louisville and in Jeffersonville but is resting on the bedrock in the northwestern part of Louisville and New Albany. Along the Ohio River bank on the northwestern side of Louisville the blue clay crops out just above the New Albany shale. The presence of blue clay is not recorded in logs of wells in other parts of the area and, therefore, may be absent. The clay was probably deposited in still wa‘er—possibly when the Ohio River was dammed at some point in its course below Louisville.

The surface materials overlying the glacial outwash deposits of the valley

are composed of clay-bound silt and fine sand which has been deposited, for the most part, during floods of the Ohio River late in the Pleistocene and in the Recent epochs and, to a lesser extent, by the smaller streams in the area. These fine-grained deposits vary in thickness from 10 to 50 ft. The banks of the Ohio River are plastered with silt and clay, and the bed of the river is silted up in part of its course.

Quality of Water

Table 1 gives the important chemical characteristics of the waters from the glacial outwash deposits and the bedrock directly beneath them. The analyses were made by the Quality of Water Division of the U.S.G.S.

TABLE 1

Range in Mineral Content of Louisville Area Ground Waters, ppm.

	Number of Analyses	Minimum	Maximum	Mean
Total dissolved solids	17	321	1,240	571
Silica (SiO_2)	17	10	21	17
Iron (Fe)	66	0.0	6.9	0.7
Calcium (Ca)	17	57	206	127
Magnesium (Mg)	17	18	63	39
Sodium and potassium (Na and K)	17	5.9	172	20
Bicarbonate (HCO_3)	66	118	534	367
Sulfate (SO_4)	66	15	371	133
Chloride (Cl)	66	3	242	34
Nitrate (NO_3)	66	0.0	60	0.6
Fluoride (F)	17	0.1	0.4	0.1
Hardness (as $CaCO_3$)	66	126	773	450

Although a few wells drawing water from the underlying consolidated formations yield water of a quality comparable to that in the glacial outwash, most wells which have been drilled into the bedrock have yielded highly mineralized water.

The water in the Ohio River has less mineral content than the ground water and is considerably softer. Its quality fluctuates somewhat with the flow of the river.

The reported temperatures of the water from over 100 wells range from about 54° to 63°F. and average 58°F. Under normal conditions the temperature fluctuates very little during the year, which for cooling purposes gives the ground water a great advantage over surface water during the summer season. The temperature of the river water ranges from a minimum of 32°F. in the winter to a maximum of 86°F. in the summer and averages about 59°F. The temperature of the river water is higher than that of ground water during about six months of each year.

Pumpage

As a part of the inventory of wells, a record was obtained of the pumpage from all the wells for the years 1937 through 1943. The survey showed that about 10 per cent of the withdrawals were metered, about 20 per cent came from wells for which the owners kept good records of operation time and discharge of the pumps, and the remaining 70 per cent came from wells for which both the periods of operation and the discharges had to be estimated.

Table 2 shows the estimated average daily pumpage by industries from wells for each year from 1937 through 1944. The table does not include an estimated 0.25 mgd. for irrigation of truck farms immediately south of Louisville. Also it does not include

TABLE 2

Estimated Average Daily Pumpage by Industries From Wells in Louisville Area, mgd.

	Number of Plants, 1944	Number of Wells in Use, 1944	1937	1938	1939	1940	1941	1942	1943	1944	August 1943	January 1944
Distilling	14	42	6.2	6.1	6.5	10.5	14.9	16.7	17.2	10.4	17.0	16.3
Rubber Manufacturing	6	39	—	—	—	—	0.2	4.6	17.0	19.9	26.9	21.8
Metal Working	15	27	1.6	1.6	1.6	1.6	3.3	3.8	3.9	3.7	4.3	3.7
Oil Refining	5	13	4.9	4.9	4.9	4.7	4.6	4.6	3.9	4.2	4.1	3.8
Brewing	3	9	5.3	5.6	5.3	5.2	4.1	4.1	3.8	3.6	3.8	2.9
Air-Conditioning, Refrigerating	93	103	4.0	4.0	3.9	3.9	3.8	3.8	3.7	3.7	8.3	1.0
Ice Making, Cold Storage	9	20	4.1	4.1	4.1	4.2	3.6	3.2	2.9	2.9	5.1	1.1
Dairying	14	21	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.2	2.4	2.1
Meat Packing	10	21	2.4	2.4	2.3	2.2	2.2	2.1	2.0	2.1	2.0	1.9
Tobacco Processing	4	10	2.5	2.6	2.5	2.2	1.9	1.7	1.2	0.9	1.7	1.0
Gas and Electricity	2	5	0.8	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.3	1.7
Food Manufacturing	14	18	0.7	1.0	1.5	1.3	1.2	1.1	0.8	0.7	1.0	0.5
Miscellaneous	20	24	1.9	1.9	2.0	2.4	2.6	2.0	1.9	1.9	2.1	1.6
TOTAL	209	352	36.6	37.3	37.6	41.2	45.4	50.8	61.5	57.0	79.0	59.4

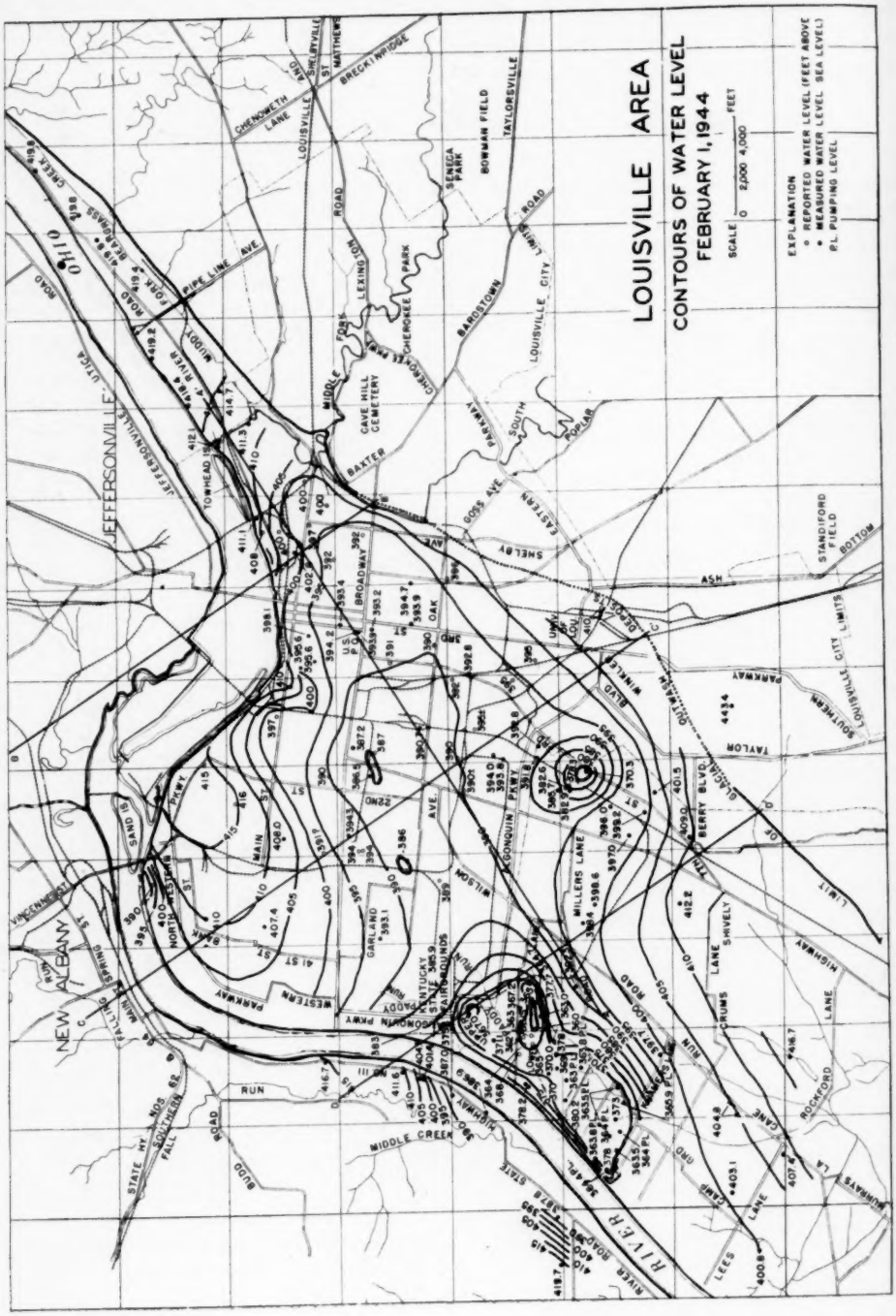
about 4 mgd. that is pumped from the glacial outwash deposits north of the Ohio River in Indiana, because it is possible that infiltration from the Ohio River makes these deposits a separate source of ground water supply from that under Louisville.

Although the pumpage is reported as the daily average for the 365 days of a year, the daily average during the summer months is estimated to be at least 10 to 20 per cent greater. The increase in pumpage during the summer is especially pronounced in the Fourth Street business district, where most of the water pumped is used for air-conditioning.

Fluctuations of Water Levels

The 1937 flood of the Ohio River covered a large part of the valley and practically filled the ground water reservoir. At Louisville, basements and sewers were flooded by the ground water. As a result many "dewatering" pumps were operated heavily and natural springs along the river developed to assist in the rapid lowering of the water table.

The principal fluctuations of the water levels in wells in Louisville and the adjoining industrial areas are caused by pumping. However, in the wells to the northeast and southwest along the river and in those located in the southern rural area the principal fluctuations of water levels are caused by natural recharge and discharge. From the Big Four Railroad Bridge northward to Harrod's Creek the water levels in wells near the river appear to fluctuate in a manner similar to the stage of the river. Another reach of the river in which water levels in wells close to the river rise and fall with the river stage is that between Lower Paddy's Run and Kosmosdale. Sufficient records are not yet available,


LOUISVILLE AREA
CONTOURS OF WATER LEVEL
FEBRUARY 1, 1944
SCALE 0 2,000 4,000 FEET
EXPLANATION
REPORTED WATER LEVEL (FEET ABOVE
MEASURED WATER LEVEL SEA LEVEL)
PL PUMPING LEVEL
JEFFERSONVILLE
NEW ALBANY
OHIO
RIVER
BROADWAY
MAIN
MARKET
OAK
GARLAND
WILSON
BAXTER
CAVE HILL CEMETERY
CHEROKEE PARK
SENECA PARK
BOWMAN FIELD
STANDIFORD FIELD
BOTTOM
PARKWAY
BERRY BLVD.
SHIVELY
RUN
MIDDLE CREEK
LOUISVILLE CITY LIMITS

however, to permit conclusions as to the amount of interconnection between the ground water reservoir and the river.

Figure 2 is a contour map of the ground water table on Feb. 1, 1944, based on 88 measured and 40 reported elevations. The map shows the several steep cones of depression in the water table caused by concentrated pumping and the direction of the movement of the water.

It is estimated that the specific yield, or effective porosity, of the sand and gravel composing the glacial outwash deposits (Fig. 1) is about 20 per cent. This means that an amount of water equivalent to a depth of 0.20 ft. is released from storage when the water table declines 1 ft. For instance, a decline of the water table of 1 ft. in 25 sq.mi. of the reservoir (which is approximately the area of the reservoir under Louisville and its immediate vicinity) represents the release of water from storage in the reservoir equal to a depth of water of 0.20 ft. over the 25 sq.mi., or an average of 2.9 mgd. for one year.

The water table has declined during the past several years in a considerable part of the reservoir under Louisville and vicinity. From records of the decline in different areas, it is estimated that of the water pumped, as shown in Table 2, the part taken from storage increased from between 5 and 10 mgd. in 1938 to between 20 and 30 mgd. in 1943.

As water has been pumped from storage, hydraulic gradients have been developed in the water table which have caused water to flow through the water-bearing materials from the areas of recharge to the areas of withdrawal; and as gradients have been developed from the recharge areas into the reservoir the rate of recharge has been increased. However, the rate of recharge has not been increased as much as the rate of pumping, and hence water has been drawn from storage at an increasing rate. Although during late 1943 the rate of pumping in the area remained about constant or slightly decreased, steeper gradients continued to be developed, with resulting declines of water levels and withdrawals of water from storage. Because of the small remaining saturated thickness of the reservoir, it is probable that the rate of recharge could not be increased to an amount equal to the rate of pumping at that time, even if the water level were drawn down until the water-bearing material would be practically unwatered.

Yield of Wells

The permeability of the water-bearing materials has been found in a few laboratory and field pumping tests to range from about 700 to about 7,000 gpd. per sq.ft. of cross-sectional area with a gradient of 100 per cent. Sufficient data are not available to permit determination of an average for the area, but it is probable that the average is between 2,000 and 4,000 gpd.

Yields of vertical wells constructed in the area during the last few years have ranged from a few gallons a minute to more than 2,000 gpm. Specific capacities (gallons a minute per foot of drawdown of water level after several hours of pumping) recorded for 70 industrial wells range from 8 to 410 and average about 60. The tendency has been to drill larger and better developed wells each year in order to obtain greater specific capacities. Had this not been true, the wells

tested in the last few years would probably have had lower specific capacities than those tested previously, for the saturated thickness of the ground water reservoir (or cross-sectional area of the conduit) has decreased. This necessitates greater hydraulic gradients and more drawdown of water level in a well for the same yield. As the depth of water in the reservoir has decreased, therefore, the yields of existing wells have decreased in greater proportion. It is estimated that the average decrease in yields of wells in the Louisville area caused by the decline of water levels in them during the last few years has been approximately 50 per cent.

Recharge

Recharge to the glacial outwash deposits comes principally from three sources: (1) infiltration from the Ohio River through its bed and banks; (2) flow from the bedrock beneath and on the sides of the outwash deposits; and (3) rainfall penetrating the surface of the river valley. Most of the recharge in the immediate vicinity of Louisville replaces water that is pumped out of the ground water reservoir. A small amount of it is discharged naturally by springs and seeps in certain places along the banks of the lower pool of the river.

The contour map of the water table in Fig. 2 shows gradients from the river to the ground water reservoir in the reach from about 1 mi. northeast of Beargrass Creek to the dam at Louisville, and in the reach of about 2 mi. along the southwestern industrial area. Fluctuations of water levels in wells along these reaches show at least a partial interconnection between the river and the reservoir. Therefore, the water from the river recharges the reservoir in these reaches. When the river is at normal stage the recharge from it to the reservoir may exceed the recharge from all other sources, and when it is in flood the recharge from it is greatly increased. More recharge from the river can probably be developed by pumping from wells located as close as practicable to the river, thus increasing the gradients from the river to the areas of withdrawal.

The limestone beneath and on the sides of the ground water reservoir is slightly to moderately cavernous and fractured, and these caverns and fractures are at least partially continuous to the outcrop of the limestone. Since the water table in the limestone is higher than the water table in the sand and gravel composing the reservoir, water entering the outcrop of the limestone flows through the openings to the sand and gravel. South of Louisville, where the area just east of the river valley is underlain by the New Albany shale or sandstones and shales of the Borden group, the sandstones and the surficial materials on the shales probably also carry some water which percolates into the sand and gravel in the valley. The gradients shown by the contour map of the water table in Fig. 2 indicate that water derived from the rocks along the eastern margin of the valley may be a considerable part of the total recharge to the ground water reservoir. More recharge from this source can probably be developed by pumping from wells located as near to the eastern margin of the valley as practicable. Since the rate of this recharge depends in part on the altitude of the water table in the rock, which is affected considerably by rainfall, the rate of recharge may be more during and immediately after periods of rainfall above normal than during and immedi-

ately after periods of subnormal rainfall. The average rainfall for 71 years at Louisville is about 42.6 in. a year, but during the years of 1938 and 1943, inclusive, the rainfall averaged about 3.7 in. less than this figure.

Recharge by direct penetration of rainfall on the surface of the valley is considered to be relatively small in proportion to the flow from the river and from the bedrock. The drainage of the area is good and the silt and clay surface materials are relatively impermeable. The recharge from rainfall in the valley is probably only significant during periods of rainfall considerably in excess of normal.

Rough computations have been made of the flow of water from the river and bedrock and of the recharge from rainfall. These show that the total recharge to the ground water reservoir probably is about 30 to 40 mgd., which, when subtracted from the 1943 pumpage figure of 61 mgd., checks the figure of 20 to 30 mgd. computed for the withdrawal from storage. Further studies are being made to verify and improve these figures.

Need for Decreased Pumping

The pumpage in and near Louisville should be reduced so that it does not exceed the recharge, and should be distributed so that yields of individual wells are held at moderate amounts by maintaining a reasonable saturated thickness wherever practicable. The pumpage should be decreased most in areas of heavy withdrawal where water levels are declining most rapidly and where the saturated thickness is small, specifically in the distillery area to the south and in the southwestern industrial area. An estimated total decrease in withdrawals of about 20 mgd. is needed in the heavily-pumped areas.

Possibilities of Additional Supplies

The means which appear to be most favorable for obtaining additional ground water supplies for the Louisville industries are: (1) induced infiltration from the Ohio River into the ground water reservoir; (2) artificial recharge of the reservoir with river water; and (3) development of the glacial outwash deposits in the rural area southward from Cane Run Ditch.

Induced infiltration from the river can be accomplished by pumping wells along the reaches of the river where the ground water reservoir and the river are interconnected. This will produce a steep hydraulic gradient from the river to the wells, causing a large part of the yield of the wells to be drawn from the river. The practicability of this method of increasing the supply is determined by the degree of interconnection between the river and the reservoir. Studies are now being made to determine the degree of interconnection in favorably situated areas.

Artificial recharge can be accomplished by introducing water into the reservoir through wells and through recharge basins. Although recharge through wells can be accomplished with ground water that has been used for cooling purposes, as is now being done on Long Island, N.Y., on a large scale, this method has the disadvantage that the recharge water is warm and would tend ultimately to raise the temperature of the water in the reservoir. Recharge through wells in the Louisville area can probably be better accomplished with river water which is not first used for cooling. Since the average temperature of the river water throughout the year is about the same

as the temperature of the ground water, the net effect on the temperature of the water in the reservoir would be negligible if equal amounts of river water were introduced in the winter and in the summer. The use of river water only in the winter when it is cold would be especially advantageous, for it would tend to lower the temperature of the water in the reservoir. Water introduced into wells should be clear and free of bacterial and other organic matter, both for sanitary reasons and to prevent clogging of the wells.

A recharge basin may be formed in the Louisville area by removing the relatively impermeable surface materials from the glacial outwash deposits. Recharge through such a basin can probably be accomplished most economically by the use of raw river water. This method has been practiced successfully in several parts of the United States. The sand and gravel between the bottom of a basin and the water table would be analogous to a slow sand filter such as is used in many water treatment plants. The suspended matter in the water would be removed within a few inches as the water would percolate from the bottom of the basin to the water table. The bacterial contamination in the water might be carried farther but would probably be entirely dissipated before it moved very far from the basin. For the best operation of a basin at Louisville, raw river water probably should be pre-settled when it is highly turbid. An experiment with a small recharge basin has been planned for the Louisville area. Whether recharge basins or wells should be used on a large scale in the area depends on the cost of introducing the water into the reservoir. If this cost, plus the cost of pumping the water out through existing wells, is less than the cost of water from other sources, artificial recharge is economical.

In the rural area southward from Cane Run Ditch, a large amount of water is probably in storage in the glacial outwash deposits of the river valley. These deposits are constantly recharged by rainfall and by percolation from the adjoining rocks and are discharging water through springs along the banks of the river. A program of exploration and observation is under way to determine the extent of the deposits and the rate at which water can be withdrawn from them without exceeding the rate of recharge.

In a few places in and near Louisville wells yielding fairly large quantities of water of good quality have been developed in the consolidated rock formations beneath the glacial outwash deposits. However, many other wells drilled into the rock have yielded only small quantities of highly mineralized water. It is probable that the water pumped from the few good rock wells is either coming from the glacial outwash deposits or is water that would recharge the deposits if not pumped. It is not believed, therefore, that the rock formations beneath the glacial outwash deposits constitute another source of large supplies of ground water. Reconnaissance studies indicate that the rock formations cropping out in and underlying the areas bordering the river valley also probably will not yield large supplies.

Emergency Recharge During 1944

The reduced yields of the wells at the National Distillers Products Corporation's Old Grand-Dad distillery and the Joseph E. Seagram & Sons' distillery have created a shortage of ground water in these plants. (The

Dant & Dant of Kentucky distillery is included as part of the Seagram distillery because of the interconnected water system and management of the two plants.)

The problem of obtaining enough ground water to maintain continuous alcohol production has been faced by these plants for more than two years. As the decreasing yields of the wells threatened to cause curtailment of production, each plant took steps toward more efficient use of the ground water, as well as toward means of augmenting the supply. Conservation of ground water was planned by cooling towers, recirculation and refrigeration. However, although plans were made in late 1943 to install the conservation equipment, a study of the construction schedules and delivery dates on the pumps, piping and heat-exchange equipment showed that the installations would not be completed until after the summer of 1944.

In March 1944 records of the decreasing yields of the wells indicated that the ground water supply would be inadequate for the summer needs. The local and Washington Office of the WPB were advised of the critical conditions involved and, through the interest of Frederick H. Weed, Regional Engineer in the production of industrial alcohol for war purposes, steps were taken to provide a temporary additional water supply for both plants until the conservation equipment could be installed.

Since additional ground water would not be available without the extensive development of a new area, the use of water from the Louisville municipal supply (at a greater cost than ground water) was authorized by the OPA. The use of city water directly from the city's system did not present a complete or permanent solution to the problem, however. The transmission capacities of the mains and the capacity of the filter plant are limited, and therefore not enough water would be available for the distilleries when other users would draw heavily during the summer. Also, in many of their processes the distilleries were designed to use ground water at 58°F. and indicated that they could not use water above 70°F., whereas the temperature of the city water usually exceeds 70°F. around June 1 and is sometimes as high as 85°F. by the middle of the summer.

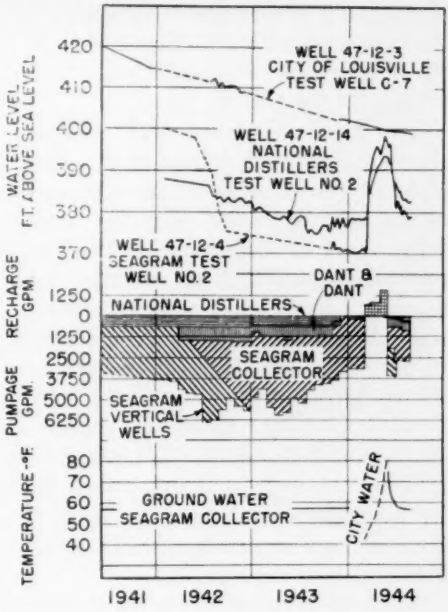


FIG. 3. Hydrographs of Typical Wells Showing Effects of Pumpage and Recharge

Water Levels and Pumpage Before March 1944

In the vicinity of the three distilleries under discussion, a large and deep cone

of pumping depression is indicated by the contours in Fig. 2. Figure 3 shows the hydrographs of typical wells in the vicinity of the plants.

The hydrograph of well 47–12–3 shows the general decline of the water table in the area about a mile south of the collector well. The rise of the water level in the spring of 1942 was probably caused by local recharge from rainfall, but the effects were soon dissipated and the water table continued to decline at the same rate as prior to the recharge.

Well 47–12–14 is in the center of the National Distillers plant, about 200 ft. from the nearest pumped well, and its hydrograph indicates the local decline of the water table within the large areal cone of depression.

Well 47–12–4 is 200 ft. southeast of the collector well and its hydrograph shows the steep decline of the water level caused by the installation and use of the collector.

Figure 3 also shows graphically the rate of pumping at the three distilleries and the rate of recharge during the spring. The pumpage at the National Distillers plants was almost constant until the diminishing yield of the wells began to limit the quantity of water that could be pumped. Prior to July 1942 the pumpage at the Seagram plant came from wells located on the west side of the plant along the railroad tracks, but after that date most of the ground water was taken from the newly-constructed collector well about 800 ft. east of the older wells. There was some increase in pumpage when the collector was put into operation as part of the water from the collector was used to augment the supply to the Dant & Dant distillery.

Shortage of Cold Water

Early in March 1944 it was determined that during June the Seagram and Dant & Dant plants would need about 4,000 gpm. of water at a temperature of less than 60°F., and the National Distillers plant would need about 400 gpm. of water at the same temperature. If this water would not be available, it was anticipated that production of alcohol would have to be curtailed. After June it was hoped to have sufficient conservation equipment installed to reduce the requirements.

Estimates made by the Geological Survey, based on the declining water table and decline in yields in the past, showed that if pumping from the wells at the plants continued, they would not yield over about 3,500 gpm. in June. The estimates also indicated that the yield of Seagram's water collector might diminish from an existing 2,800 gpm. to between 2,500 and 2,200 gpm. by the end of summer, and that the yields of the three wells at the National Distillers plant would decline materially below their 200 gpm. each.

On the other hand it was estimated that 4,400 gpm. of ground water could be made available during June if the water table could be raised enough before then to increase considerably the saturated thickness of the water-bearing materials. To permit the water table to rise, it was decided to stop using ground water at the three distilleries and to allow the water levels to recover through the natural recharge flowing into the area. A series of computations was made by the Geological Survey from which it was estimated that, if all the pumping for the National Distillers and Seagram plants

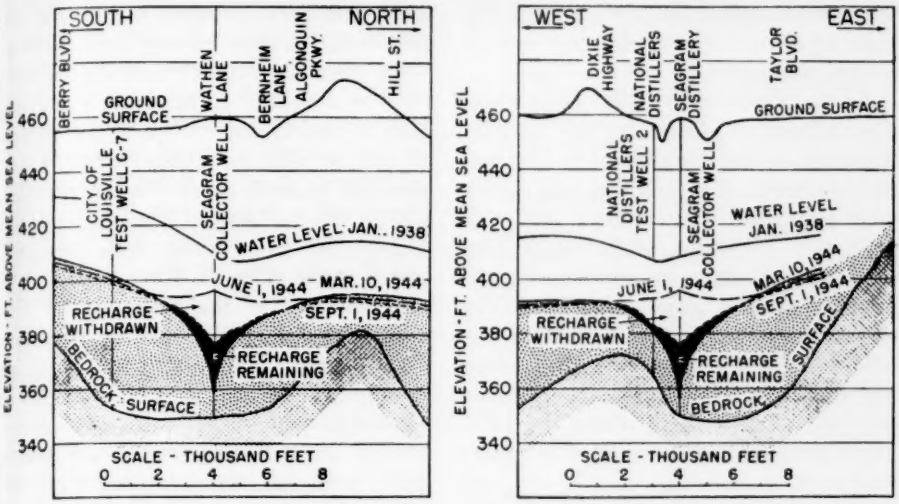


FIG. 4. Geological Sections Through Collector Well
(a) North-South Section, (b) East-West Section

were stopped for 90 days, the ground water levels would recover sufficiently to allow the required amount of water to be pumped from the wells for one month. To provide a factor of safety and assist in the recovery it was decided also to recharge city water to the Seagram's collector well and to two wells at the National Distillers plant. The use of ground water was stopped and the recharge of city water was started on Mar. 10, 1944.

The darkened area in Fig. 4 represents the rise of the water table caused by cessation of pumping from March 10 to June 1, plus the addition, during this period, of city water to the collector well at an average rate of about 1,130 gpm. and to the wells at the National Distillers plant at an average rate of about 200 gpm. Figure 3 shows that the natural recharge was considerably greater than the artificial recharge.

The temperature of the ground water in sixteen wells in the vicinity of these distilleries was 57°F. early in March. The weighted mean temperature for all the water artificially recharged from March through May was 58.5°F., or about the same as the natural temperature of the ground water.

Late in April, a recapitulation of the construction schedules and equipment delivery dates showed that the conservation equipment would not be in operation before July 1, when it had been estimated that the yields of the wells would become less than the demand of the distilleries. On May 2 the engineers of the distilleries, the WPB, and the Geological Survey conferred on the provision of additional means of maintaining a continued supply for each plant.

At the Seagram plant steps were taken to: (1) recharge city water to the ground at a greater rate; (2) hasten the completion date of the installation of the water conservation equipment; (3) provide more city water to supplement the ground water during the summer; and (4) change

the operational procedures within the plant to allow the use of water with a temperature of 70°F.

At the National Distillers plant steps were taken to: (1) hasten the completion date of the installation of the water conservation equipment; (2) provide additional city water; and (3) drill two 150-gpm. wells south and west of the plant to supplement the present ground water supply. The two new wells would be drilled to distribute the pumpage over a larger area and thus eliminate as much as possible the cone of depression where the saturated thickness of the sand and gravel was thin.

The computations indicated that the water levels in most of the wells at the National Distillers and Seagram plants would be below the pump intakes after 60 days of continuous pumping from the wells at the total rate of 4,400 gpm. This did not mean a failure of the ground water supply, however, but meant that the yields of the wells would be maintained at 4,400 gpm. for only about 60 days and then the yields would decrease as the water levels could no longer be lowered. The computations indicated that, if the combined pumpage for the plants were less than 4,000 gpm., the water levels in most of the wells would be maintained above the pump intakes during at least 90 days of continuous pumping.

Early in May 1944, the actual rise of the water level caused by shutting down the wells and recharging through them was very close to the rise that had been computed by the U.S.G.S., indicating that the assumptions made in the computations regarding permeability and effective porosity of the water-bearing materials were nearly correct. These assumptions were that the permeability is equal to 2,500 Meinzer units * and the effective porosity is 20 per cent. These assumptions having been checked, it appeared that the rest of the original computations should also be nearly correct—that the plants would be able to pump about 4,000 gpm. of ground water for the remainder of the summer if the use and recharge of city water were stopped about the middle of May.

According to the estimates of demand, however, this quantity of water (4,000 gpm.) would still not be quite enough. The officials of the plants agreed to make several changes in the plants, so that they could use water with a higher temperature than was formerly possible. City water, therefore, was continued in use at the Seagram and Dant & Dant plants until June 3, even though at that time its temperature was nearly 80°F. Pumping was begun again from some of the National wells on May 17. During the summer, the plants used a mixture of city water and ground water.

So effective were the ground water conservation measures practiced at these plants that the total demand during the summer averaged only about 3,000 gpm. instead of the 4,400 gpm. originally estimated. As a result, the plants had a reserve of cold ground water at all times during the summer and could pump at considerably higher than average rates for short periods.

If practicable from the standpoint of the cost of the city water, a satisfactory solution to the entire shortage of ground water in Louisville would be for a large number of industries to use city water in the winter, and, at the

* The unit of permeability or Meinzer unit, in gpd., is the rate of flow through a square foot cross-section of a given material under a hydraulic gradient of 100 per cent or one to one at a temperature of 60°F.

same time, recharge the ground water reservoir with the cold city water, pumping their wells only in the summer. If this were done on a large enough scale, it would not only stop the perennial decline of water level, by making the recharge equal to the discharge from the ground water reservoir, but also would allow wells to be pumped at much greater rates during the summer than will be possible if they are used continuously.

Future Conservation Plans

Before the Geological Survey started its work, the conservation of ground water had been urged by the WPB, the well drillers in the area, the War Products Advisory Committee and other interested agencies. After the Geological Survey collected data to show that conservation on a large scale in a short time was absolutely necessary and after the Underground Water Users Association was formed efforts to bring about the reduction of pumpage were redoubled. Many large organizations, both governmental and private, co-operated.

At first it was thought that ground water would have to be piped into Louisville from adjoining areas in order to allow the industries to continue full production and at the same time reduce the pumpage from their present wells. Because of the rapidly decreasing yields of wells, however, and because no major development in an adjoining area was yet planned, each industry facing a shortage began to solve its own problem. Gradually, ways and means to reduce the consumption of ground water were found. These include more careful use of water, changes in manufacturing processes, recirculation, refrigeration, use of cooling towers, use of river water, use of city water, artificial recharge and use of more wells along the river to increase infiltration from the river. Each of these conservation measures is now being practiced or is planned by one or more industries in the Louisville area.

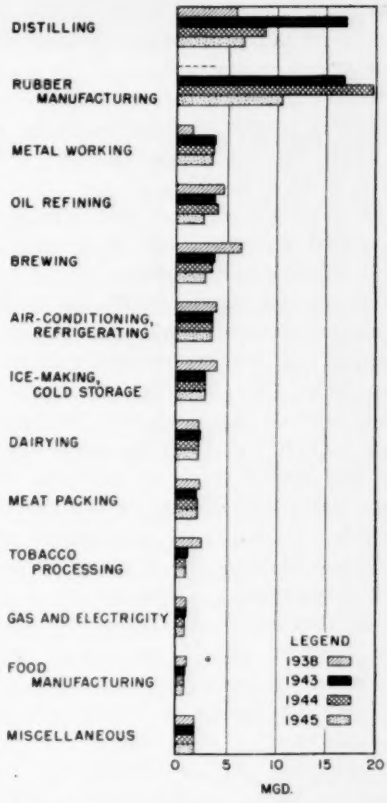


FIG. 5. Estimated Average Daily Pumpage by Industries From Wells

When the installations that have been planned are completed, several million dollars will have been spent in the effort to reduce the pumpage of ground water. By means of these conservation measures the withdrawal of ground water in the Louisville area in excess of the rate of recharge will soon be largely stopped and the present emergency will have been met successfully. It is understood from the WPB

that no industry at Louisville has yet had to curtail production because of a shortage of water.

Figure 5 shows the estimated average daily pumpage from wells by industries in Louisville during 1938, 1943, 1944 and 1945.

Most of the conservation measures described are still only contemplated. Also, because the estimates of recharge are necessarily approximate, the underground reservoir may still be overpumped by several million gallons a day even after all the contemplated conservation measures are in operation. Then, too, after the areal shortage has been solved, several local sections will probably still be pumped too heavily and a more satisfactory distribution of pumpage in those sections will be needed. Therefore, it is believed that efforts to reduce the pumpage further should not cease until conservation measures have actually stopped the decline of the water table in every section of the area.

Two programs of test drilling have been proposed in areas adjacent to Louisville where additional ground water might be obtained. One of these is in the Ohio River Valley to the southwest of Louisville and one in the valley to the northeast. It is still believed that these programs should be carried out. The inventory of the ground water resources of the Louisville area cannot be completed until more information is available. If large quantities of ground water are available in one or both of these areas, they will be of great value to the future industrial growth of Louisville.

References

The foregoing records, which have been excerpted from the various U.S. G.S. reports listed below, are intended to give a general picture of the ground water situation in the Louisville area. Readers who wish to study these conditions further may obtain copies of the reports by addressing the U.S. Department of Interior Geological Survey, 531 Federal Bldg., Louisville, Ky.

1. Guyton, W. F., Stuart, W. T. & Maxey, G. B. Progress Report on the Ground Water Resources of the Louisville Area, Kentucky. March 1944.
2. Stuart, W. T. Conservation of Ground Water, Including Artificial Recharge, by Two Companies in the Louisville Area, Kentucky. July 1944.
3. Hamilton, D. K. Ground Water in the Bedrock Beneath the Glacial Outwash in the Louisville Area, Kentucky. August 1944.
4. Guyton, W. F. & Sublett, H. E. Conservation of Ground Water in the Louisville Area, Kentucky. October 1944.
5. Chemical Analyses of Water From Wells in the Louisville Area, Kentucky. November 1944.

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DISCUSSION—*B. E. Payne*

Chief Engr. & Supt., Louisville Water Co., Louisville, Ky.

Although the Louisville Water Company obtains its water supply from the Ohio River and is not dependent on ground water, it has been materially affected by the measures described in the foregoing report. The demand upon its entire production and distribution facilities caused by the depletion of this underground supply of industrial water can best be shown by a comparison of the average daily pumpages by months for the last six years in million gallons daily.

Months	*1939*	*1940*	*1941*	*1942*	*1943*	*1944*
January	40.5	50.9	42.4	47.2	48.1	53.8
February	40.5	46.5	41.8	44.0	48.4	52.7
March	40.5	40.7	41.1	43.1	49.1	56.7
April	38.4	39.3	43.0	45.0	48.3	60.1
May	44.3	40.4	49.1	47.8	49.2	64.7
June	46.0	44.7	50.2	51.2	57.1	70.3
July	49.1	50.3	53.2	54.0	61.4	69.1
August	47.2	50.2	53.4	52.9	64.6	64.5
September	48.9	44.6	50.2	50.4	57.9	59.8
October	44.5	44.0	46.0	48.4	55.9	59.5
November	43.0	42.1	44.2	47.1	54.0	56.3
December	41.2	40.8	43.5	48.6	52.9	54.6
Yearly Average	43.7	44.5	46.5	48.3	54.0	60.2

It will be noted that increases from year to year were more or less normal until 1943, when the industries first began to substitute the city supply for that obtained from underground, and the abnormal increases in March, April, May and June of 1944 can be attributed to the intensification in those months of the campaign to conserve the underground supply. It is estimated from these records and from a summary of actual water meter readings of industrial consumers that 15 mgd. were used for this purpose during the spring of 1944.

This sudden and unforseeable increase demonstrated certain weak spots in the company's plant. The high daily demands during the spring months when the turbidity of the river water was at its maximum resulted in temporarily overloading the coagulation capacity and a cloudy filtered water was produced for several days in March 1943 and again in 1944. A new and modern system of flocculation, clarification and chemical handling is now under construction, and is planned for completion before the spring of 1946. Until then the closest control and maximum chemical usage will have to be continued.

The pumping capacity of the company, which had been increased after the 1937 flood, proved very adequate. In fact, the extreme loads of March and April 1944 were handled with two units, or a total capacity of 64 mgd., out of service for repairs.

The distribution system, augmented by the twelve-year-old 30-mil.gal. elevated reservoir, received a real test during June when this war-induced industrial demand was superimposed on an extreme dry weather lawn-sprinkling peak load. Rain storms on July 2 and the following holiday were all that prevented a water rationing campaign in Louisville. A maximum hourly consumption rate of 131 mgd. was reached, with a maximum day of 79 mgd. on June 28.

The unprecedented demand by large industrial services for supplying the new war industries and by the older users of well water severely taxed the ability of the company to obtain the necessary meters, valves and other materials. (Twenty-four 6-in., one 8-in. and two 10-in. services were installed during 1943 and 1944.) The War Production Board was particularly helpful but even this body could not provide large meters as fast as they

were needed. One 10-in. service was installed using a battery of six 4-in. meters. When these proved inadequate, three 6-in. Crest meters were borrowed from three public swimming pools inactive at the time. Later, when even more flow was demanded of this particular service, an existing plant orifice meter was calibrated against the 6-in. Crest meters. Then two of the meters were removed and nipples substituted. The remaining 6-in. meter flow was then compared with the orifice meter and a factor obtained which was used with this 6-in. meter to measure the consumption. An adequate flow of 5,600 gpm. was thus obtained. This borrowing a meter from an inactive service and replacing it with a new meter when received was repeated several times and several other makeshifts were satisfactorily devised.

The Louisville Water Company, through its chief engineer, has been active in the Louisville Underground Water Users Association in an effort to work out some solution to this failure of the ground water supply. Several ideas have been advanced but the only other source immediately available seems to be from the facilities of this company.

The best plan appears to the company to be that of using the water supply from the city system during the winter months from October through April when it is cool enough; recharging the underground pool where possible during this period; and conserving the use of all industrial cooling water by every means, thus saving the underground storage of cool water for summer use. While the cost of city water is in excess of that obtained from wells, the rate in effect in the Louisville area is lower than that of any surrounding community. The yearly load curve is such that, with the completion of the new treatment facilities now under construction, the company will be able to make up for most of the deficiency in the ground water supply for normal uses.

With this in mind the Louisville Water Company is building and planning to build up its system so that there will be no doubt of its ability to supplement the ground water supply to such an extent. It is also contributing substantially to the cost of the surveys now being made to develop new sources of underground water.

This publicly-owned water utility believes that its function is to grow with the community and do everything in its power to satisfy the needs of that community in the water supply field. Just as the excellent forehandedness exerted in the past has enabled us to contribute to the solution of this serious war production problem, ways and means will be forthcoming to solve a similar problem in peacetime.

Ground Water Problems in New Jersey

By Henry C. Barksdale

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Presented on Nov. 9, 1944, at the Four States Section Meeting, Philadelphia, Pa.

TWENTY-ONE years ago, in July 1923, the state of New Jersey entered a co-operative agreement with the U.S. Geological Survey. That agreement provided for a *quantitative* investigation of the ground water resources of the state. At that time, and for some years thereafter, this investigation was the only continuing quantitative study of ground water conditions in any of the eastern states. A few years later, quantitative work was begun in New York and in recent years it has been rapidly extended to nearly every state on the eastern seaboard.

One might think that the New Jersey program, having come of age, would have very few problems left, but the opposite is true. We are continually finding new problems and our old ones show a remarkable tendency to grow.

Some time prior to 1923 the ground water problems in the state were essentially one-well problems; that is, they involved answers to questions as to where and how deep to drill, and how much water might be obtained from a single well. By 1923 the problems had grown into areal ones involving the safe yield of specific aquifers in limited areas of heavy pumping, such as Atlantic City, Camden, Asbury Park or Parlin. As we studied these problems it became increasingly apparent that that was not always enough. The safe yield at Asbury Park might be affected by pumping at Parlin or vice versa. The pumping at Atlantic City might affect the safe yield up the dip in the same formation at Egg Harbor or at Hammonton or vice versa. Thus, it has become apparent that it is necessary to know the safe yield of the whole aquifer and the safe distribution of pumpage in it, and the problem in New Jersey has grown from a single well to an aquifer covering half a state or perhaps two or three states.

Originally the quantitative ground water studies in New Jersey were limited to a few very small areas in which critical problems appeared to exist. These areas are still being studied. Six formal reports (1, 2, 3, 4, 5, 6) on these areas were issued as well as a number of shorter papers. Gradually the intervening spaces have been filling with question marks and the scope of our investigations has expanded. We recently issued our first report covering an entire county (7). The county report, it is felt, has an advantage over the report on a limited area in that it provides a way of covering the less developed areas along with those in which heavy pumping and other serious problems may exist. It leaves less room for the question marks and brings us nearer to the time when we can study the aquifers as a whole and evaluate the supply of ground water on a state-wide basis.

Geology

New Jersey has a wide variety of geologic formations ranging from hard crystalline rocks that contain very small quantities of water in occasional cracks to coarse clean sands and gravels that contain abundant supplies of water. Intermediate materials, such as limestones and fractured shales and sandstones, cover wide areas in the central and northwestern part of the state where the crystalline rocks are also found. The southeastern part of the state, perhaps three-fifths of its total area, is covered by coastal plain deposits which are composed of alternating layers of sands and clays. Some of the coastal plain sands are the most important aquifers. However, some of the rocks in the northern and western parts of the state yield very large quantities of water, particularly where they are covered by glacial deposits that help to absorb and store water for recharging the rocks. In many places where they are coarse and well sorted, the glacial deposits themselves yield substantial quantities of ground water.

Safe Yield

The safe yield of an aquifer is limited by its capacity to absorb, to store, to transmit water and by its exposure to salt water or other contaminating materials that may make the quality of its water unsatisfactory. Whichever of these factors permits the smallest amount of water to be drawn from the aquifer determines its safe yield. When these four things are known about an aquifer its safe yield can be determined. We are still a long way, however, from such positive knowledge about most of the New Jersey aquifers, and it cannot be said that we know absolutely the safe yield of any of them.

The capacity of an aquifer to store and transmit water is determined by the size, number and nature of the pore spaces or cracks in which the water is stored and through which it moves. These characteristics are fixed by nature and are reasonably susceptible to measurement. A knowledge of them is most helpful in determining the safe yield of an aquifer. For example, a comparison was recently made between these two factors in one of the better coastal plain sands and in the fractured shales of the Brunswick formation (*7*). The sand, it was found, could transmit about four times as much water as the shale at any given hydraulic gradient. It could store twenty times as much water as the shale. Apparently, the safe yield of the shale was more likely to be limited by its storage capacity than by its capacity to transmit water. Experience has shown this to be true. The safe yield of the shale is relatively low except where some source of continuous recharge is available. The amount of water stored in the cracks in rock is not enough to sustain a large yield between periods of precipitation.

The capacity of an aquifer to absorb water and its exposure to contamination are less susceptible to exact measurement than are its transmissibility and its storage capacity. Furthermore, they are susceptible to change by the works of man. On these facts are based two whole families of problems, namely, how to evaluate these factors and what are or may be the effects of the works of man.

The results of research seem to indicate that the capacity of most aquifers to absorb water is large and that

this factor in itself seldom limits the safe yield. Intake opportunity, on the other hand, frequently limits safe yield. By intake opportunity is meant the favorable combination of circumstances that provide water for recharging an aquifer at a time when there is storage space within the aquifer to receive it. Probably all of the aquifers in New Jersey refuse some recharge at times of heavy precipitation, simply because their storage space is used up. This is particularly true of rocks, such as the Brunswick shale referred to above, which have relatively small storage capacity. When water from precipitation is available for recharging them, these aquifers are soon filled and much of the water must run off over the surface. The evaluation of problems of this nature must still be largely a matter of judgment and experience.

Where the intake capacity of an aquifer is greater than its intake opportunity, as is generally the case, it may be possible to enlarge its safe yield by artificially recharging it. Artificial recharge has been practiced for many years in some areas in New Jersey. The practice is increasing as it becomes apparent that the safe yield of some good aquifers is being limited by their natural rates of recharge.

The Perth Amboy Water Department was one of the first in the state to recognize the value of artificial recharge and to construct works for recharging the principal aquifer in the well field at Runyon (7). Originally this system consisted merely of a dam and pond on a small stream flowing through the well field. From time to time the system has been enlarged until there is now an elaborate system of channels and basins to spread surface water over the area drawn upon by the wells and practically the entire flow of the stream is used to recharge the sand. Some water for recharging is also drawn from another stream nearby.

Artificial recharge is also being practiced at Princeton where water is pumped from a stream and spread over the area adjacent to the wells, at the East Orange Water Works (8) and at the Duhernal industrial (7) water supply near Old Bridge. The quantities of water introduced into the ground at each of these localities probably range from one to several million gallons daily. In some cases, where adequate quantities of surface water are available, this amount may be increased materially as the need arises.

Salt Water Intrusion

The danger of salt water intrusion into fresh water aquifers is one of the most serious problems with which we are faced in New Jersey. Along the shore where the aquifers are exposed both to salt water recharge and to fresh water recharge, nature has set up a delicate balance between the two kinds of water in the aquifer. When man disturbs this balance by pumping out the fresh water he invites the salt water to move into his well.

In the Atlantic City area for example, the head of the water in the so-called Atlantic City 800-ft. sand, was originally about 25 ft. above mean sea level. Heavy pumping has lowered the head in this sand below sea level for 20 or 30 mi. along the shore. In the centers of heaviest pumping the head is now as much as 75 or 100 ft. below sea level. Little is known, of course, of the geology of this sand in the direction of the ocean, but it seems probable that the initial head was enough to hold the salt water in bal-

ance at a point about 7 mi. off shore. This balance has now been reversed and salt water is almost surely moving toward the Atlantic City area as fast as the intervening volume of fresh water can be removed.

Other areas in which salt water intrusion is occurring, or is threatened, may be found all along the coast—at Perth Amboy, South Amboy, Sayreville, Cape May and Penns Grove, to name but a few localities. Nearby in Delaware the water supplies of Lewes and Rehoboth Beach are also endangered by the encroachment of salt water. Problems relating to salt water encroachment are, in fact, common to all the coastal states. Their solution requires careful study and intelligent operation. It is generally far easier to avoid salt water intrusion than to overcome its effects.

The removal of water from an aquifer by pumping is only one of the ways in which man can and does disturb the balance between the fresh water and salt water in exposed aquifers. Works such as canals, dams and reservoirs also can and do affect this balance. The construction of a canal containing salt water through a fresh water aquifer obviously introduces a new source of salt water recharge. A canal containing fresh water, on the other hand, may be either beneficial or harmful, depending largely upon whether the aquifer is drained into the canal or receives recharge from it. Dams and reservoirs usually tend to restrain the advance of salt water both by blocking its advance into existing channels and by creating a higher fresh water head. The construction of suitable fresh water reservoirs is one of the best-known means of combating the intrusion of salt water into exposed aquifers. Such works have been suggested as possible remedial measures near Atlantic City and Old Bridge, N.J.

Need for Regulation

Another item which must be included in the list of ground water problems in New Jersey is the tendency toward heedless overdevelopment. The author feels that this problem is one of the most serious and urgent of the ground water problems along the entire eastern seaboard. Mention has been made of the one-well problems that predominated the ground water picture in New Jersey many years ago. Too many of us are still concerned only with how much water we can get right now from our own wells without much thought of the safe yield of the aquifer, which determines the permanency of the supply.

Conditions in some parts of Newark, in which there are a great many industrial wells, provide a good case in point. The competition for the water that is available there is exceptionally keen. Property owner "A" drills a well on his land and begins using water from it. His neighbors "B" and "C" drill wells on their properties and pump so much water that "A" can no longer get enough from his well. "A" then deepens his well or lowers his pump and draws the water from "B" and "C." This process is repeated again and again throughout the area with the result that the water level is drawn down, down, down, and ultimately there may not be enough good water left for any of them.

All too often the development of ground water resources has been carried on with little, if any, consideration of the possibility that the safe yield of the various aquifers might be exceeded. This has been due primarily

to public ignorance of the nature of the problem. The scientific quantitative study of ground water problems is still relatively new and, although great advances have been made, it is not yet possible to arrive at very exact results. It now appears that certain aquifers in New Jersey have been over-developed and that the development of others is probably approaching their safe yield. Nevertheless, a great majority of the people still think in terms of the many successful developments that were made in the past and assume that more and more water can be drawn from the same aquifers by the simple process of drilling more wells. Communities vie with one another for new industries and the assurance is freely given that plentiful water supplies are available. The tremendous amount of water held in storage in the productive aquifers makes each new development appear successful and safe. Only after years of pumping may the effects of heedless overdevelopment become evident. When that occurs the industries so eagerly sought can, and probably will, move to other areas, leaving the community poorer not only in industrial development but very possibly in water resources also.

New Jersey is by no means unique in this respect. In the humid eastern part of the United States there is a widespread tendency toward heedless overdevelopment of ground water aquifers, especially for industrial use. This tendency is fostered by public indifference to the problem and by a general belief that the supply of ground water is inexhaustible. It is aggravated by antiquated laws and legal principles that do not permit adequate control of the withdrawal of ground water for private or industrial uses. In many areas the situation has become so serious that the public interest demands impartial control of all withdrawals of ground water. In the more arid western part of the country the value and limited nature of the ground water supply have been somewhat more generally recognized and effective legal action has been taken in a few western states to protect it from destructive overdevelopment.

If carefully developed our ground water supplies will last indefinitely. On the other hand, if wantonly and wastefully overdeveloped, they may be destroyed altogether or their usefulness may be very much impaired. The extent of their development can no longer safely be decided solely on the basis of how profitable it may be or how desirable a new industry that is dependent upon a supply of ground water may seem. In the public interest the maintenance of a rate of withdrawal that will assure the permanency of the supply should be the first consideration in passing upon any proposed new development. A continuous, though limited, supply of ground water is much more valuable than a larger supply that may be taken from the aquifer for a brief period of years.

It is beyond the scope of this paper to suggest the form that the regulation and control of ground water development should take. Nevertheless, it should be pointed out that in the final analysis the critical factor will be the safe yield of whole aquifers rather than of small parts of them. Regulation of the ground water developments in one county, for example, would be helpful but much of its value might be destroyed by unregulated development of the same aquifers in adjacent counties. Effective control should therefore be state-wide and the regulation of interstate aquifers will require in-

terstate co-operation. Effective control should also be broadly inclusive. Restrictions applied to one class of water users (for example to public water supplies) and not to another would be futile as well as unfair. No diversion of ground water should be made without the prior approval of some unbiased agency empowered to safeguard this valuable natural resource against injurious overdevelopment.

References

1. THOMPSON, D. G. Ground Water Supplies of the Atlantic City Region. N.J. Dept. Conservation and Development, Bul. *No. 30* (1928).
2. ———. Ground Water Supplies in the Vicinity of Asbury Park. N.J. Dept. Conservation and Development, Bul. *No. 35* (1930).
3. ———. Ground Water Supplies of the Camden Area. N.J. Dept. Conservation and Development, Bul. *No. 39* (1932).
4. ———. Ground Water Supplies of the Passaic River Valley Near Chatham, N.J. N.J. Dept. Conservation and Development, Bul. *No. 38* (1932).
5. BARKSDALE, H. C., SUNDSTROM, R. W. & BRUNSTEIN, M. S. Supplementary Report on the Ground Water Supplies of the Atlantic City Region. N.J. State Water Policy Com., Special Rpt. 6 (1936).
6. ———. Water Supplies From the No. 1 Sand in the Vicinity of Parlin, N.J. N.J. State Water Policy Com., Special Rpt. 7 (1937).
7. BARKSDALE, H. C., JOHNSON, M. E., BAKER, R. C., SCHAEFER, E. J. & DE-BUCHANANNE, G. D. The Ground Water Supplies of Middlesex County, N.J. N.J. State Water Policy Com., Special Rpt. 8 (1943).
8. ROPER, R. M. Ground Water Replenishishment by Surface Water Diffusion. Jour. A.W.W.A., **31**: 165 (1939).

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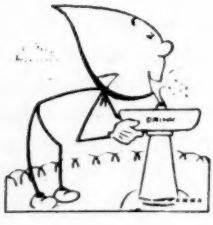

Methods of Salt Water Disposal in Oil Fields

By W. S. Morris and Samuel F. Peterson

EAST TEXAS OIL FIELD—*W. S. Morris*

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Presented on Oct. 19, 1944, at the Southwest Section Meeting, Austin, Tex.

THE East Texas oil field is a water drive field. Small amounts of salt water were produced from wells on the west side of the field from the beginning of the development. The field was discovered in September 1930, and by the end of 1933, water production had reached 9,000 bbl. per day. By the end of 1936, approximately 2,000 wells were producing about 45,000 bbl. of water per day. It was at this stage of development that the problem of salt water disposal attracted the serious attention of the operators. Salt water production in the field has steadily increased and today approximately 450,000 bbl. of water per day is produced while the oil production averages about 375,000 bbl. The disposal of salt water in the field has therefore become one of the major operating problems.

Methods of Salt Water Disposal

Various methods of salt water disposal have been tried in the East Texas field. The evaporation of salt water in open pits proved to be impractical, primarily because the rate of rainfall approximated the rate of evaporation. The evaporation of salt water with the aid of artificial heat proved too expensive a method. The volume of salt water was too great to permit the continuous discharge of salt water into streams in the field. The cost of providing a salt water disposal line to the Gulf Coast was too great to be attractive. For a period of time, salt water was stored in large earthen reservoirs and released into streams during periods of heavy rainfall. While this method was partly successful, the program was difficult to supervise and, in addition, too many pits were required to store the large volumes of water during periods of drought. The disposal of salt water by injection into subsurface formations was believed possible and early in 1936 the method was successfully demonstrated in an experimental well located west of the East Texas field.

Development of Subsurface Disposal

The first subsurface salt water disposal plant in the field was installed in 1938. The feasibility of the method was recognized and other projects were started. The second subsurface disposal project was put into operation in March 1939, and by the end of that year ten systems were in operation. During 1940, 21 additional systems were completed. The number of plants in operation by years is shown in the following tabulation:

Year	Salt Water Injected Into Woodbine Sand bbl.	Daily Average bbl.	Injection Wells
1939	2,250,761	6,166	10
1940	10,965,939	29,962	31
1941	23,530,319	64,467	47
1942	29,635,976	81,194	49
1943	73,622,778	201,706	64
1944 (9 months)	90,591,599	330,626	74

Over 230,000,000 bbl. of salt water have been returned to the Woodbine reservoir in the East Texas field since the first well started operation in June 1938.

The subsurface injection of salt water in the East Texas field has had a dual purpose: first, the return of the water to the subsurface formation practically eliminated the pollution problem; and second, the return of salt water to the lower part of the Woodbine reservoir has maintained the bottom hole pressure to a remarkable extent.

Maintenance of Pressure

In the East Texas oil field, petroleum technologists had determined, from years of study of the performance record of the field, that the total withdrawal of oil and water from the field should not exceed 650,000 bbl. per day if the reservoir pressure were to be maintained. The maintenance of a relatively high reservoir pressure is desirable for two principal reasons: first, the dissolved gas in the oil does not come out of solution until the pressure is reduced below 740 psi. and while the gas is dissolved in the oil the viscosity is low, so that the oil is able to move through the pores of the sand with facility; second, when the pressure is high enough to force the oil to the surface, the oil is produced without the use of mechanical equipment. The elimination of artificial lift equipment is in itself a very important factor because of the difficulty of obtaining necessary equipment. The production of a barrel of water has approximately the same effect on the reduction of reservoir pressure as the withdrawal of a barrel of oil. Consequently the water should be either kept in the ground or returned to the reservoir.

Another important element in the matter of salt water disposal in the East Texas field is the question of the pollution of streams. Salt water kills all vegetation and makes fresh water unfit for domestic or industrial use. The disposal of approximately 400,000 bbl. of salt water per day in the field was in itself a considerable problem.

Confronted with the necessity of disposing of the salt water to avoid surface contamination and the necessity of maintaining the reservoir pressure, the oil operators in the field studied the possibilities of organizing a company to take care of both problems from a field-wide standpoint. As a result of much study and co-operation between the smaller companies and larger companies, it was finally decided to organize the East Texas Salt Water Disposal Co., with a capital of $2,000,000. The corporation was perfected in August 1942, with 249 subscribers to stock, representing ownership of over 16,500 oil wells in the field. This co-operative organization of seventeen large companies and 232 smaller operators, was an outstanding achievement in itself. The project had the endorsement of the Railroad Commission of Texas (the oil regulatory body in the state) and the Petroleum Administration for War. High priorities were assigned to the project so that it would be possible to obtain the necessary materials.

TABLE 1

Salt Water Injected by East Texas Salt Water Disposal Co.

Month	Facilities Furnished		Injection Wells	Water Injected, *bbl.*	
	Leases	Wells		Month	Daily Average
1942					
October	4	29	1	91,670	2,957
November	11	80	2	172,942	5,765
December	27	208	8	323,995	10,451
TOTAL 1942				588,607	6,398
1943					
January	64	443	16	710,235	22,911
February	117	734	17	1,240,094	44,289
March	139	897	20	1,743,650	56,247
April	236	1,360	24	2,383,047	79,435
May	266	1,502	26	2,928,503	94,468
June	270	1,543	26	3,149,998	105,000
July	290	1,644	25	3,640,251	117,427
August	311	1,781	26	3,845,285	124,041
September	340	1,939	27	4,375,650	145,855
October	334	2,031	28	5,159,557	166,437
November	356	2,010	30	5,373,495	179,116
December	382	2,100	30	6,043,907	194,965
TOTAL 1943				40,593,672	111,216
1944					
January	410	2,135	31	6,243,047	201,389
February	422	2,259	33	6,031,829	207,994
March	419	2,243	33	6,449,001	208,032
April	440	2,369	31	6,412,917	213,764
May	445	2,260	32	6,314,692	203,700
June	454	2,303	32	6,239,956	208,665
July	458	2,323	32	6,587,297	212,493
August	461	2,354	34	6,792,439	219,110
September	472	2,411	34	6,897,687	229,923
TOTAL—9 Months				57,988,865	211,638

Mechanics of the Project

Prior to the organization of the East Texas Salt Water Disposal Co., several large operators had installed salt water disposal plants of their own to serve their individual properties. Water produced by other operators was not taken into these systems. The company drilled wells at strategic points, installed treating plants and extended its gathering lines to all operators in the field, regardless of whether they owned stock in the corporation. The company is set up in the nature of a public utility with the same rates of service to everyone.

The salt water is taken directly from the lease tanks, transported through asbestos-cement pipelines to central

TABLE 2

Salt Water Produced and Injected—East Texas Field

Month	Salt Water Produced, *bbl.*		Salt Water Injected, *bbl.*		Percentage Injected	Producing Days
	Month	Daily Average	Month	Daily Average		
1942						
October	11,654,946	375,966	2,696,220	87,000	23.14	22
November	11,215,860	373,862	2,667,973	88,933	23.79	21
December	12,214,000	394,000	2,954,901	95,319	24.19	22
1943						
January	11,505,960	371,160	3,163,849	102,059	27.50	20
February	10,493,028	374,751	3,493,127	124,755	33.29	18
March	11,787,564	380,244	4,248,994	137,064	36.05	20
April	11,721,600	390,720	4,824,863	160,829	41.16	21
May	12,007,385	387,335	5,478,541	176,727	45.63	21
June	11,620,050	388,459	5,727,688	190,923	49.15	20
July	12,738,551	410,921	6,465,220	208,555	50.75	23
August	12,961,038	418,098	6,663,214	214,942	51.41	23
September	12,369,900	412,330	7,306,248	243,542	59.06	23
October	12,785,392	412,432	8,245,351	265,979	64.40	23
November	12,799,290	426,643	8,494,446	283,148	66.37	23
December	13,257,243	427,653	9,511,129	306,811	71.74	23
TOTAL (1943)..	146,047,001	400,129	73,622,670	201,706	50.41	—
1944						
January	12,188,234	393,169	9,696,855	312,801	79.56	23
February	11,730,136	404,487	9,440,126	325,522	80.48	23
March	12,555,000	405,000	10,093,056	325,582	80.39	23
April	12,450,000	415,000	9,895,010	329,834	79.48	22
May	13,020,000	420,000	9,975,973	321,806	76.62	23
June	12,450,000	415,000	9,851,262	328,375	79.13	22
July	13,020,000	420,000	10,454,856	337,253	80.29	23
August	13,175,000	425,000	10,596,774	341,831	80.43	24
September	13,050,000	435,000	10,587,687	352,923	81.13	23
TOTAL.....	113,638,370	414,739	90,591,599	330,626	79.72	—

treating plants and then returned through injection wells below the oil water contact of the Woodbine sand.

The company began its actual field operations in October 1942, and has shown consistent progress since that time, as evidenced by the data shown in Table 1. At present the company has 32 salt water injection wells in operation and three additional ones under construction. Its lines extend over a distance of more than 40 mi. on the west side of the field where water is produced. Its total gathering system measures more than 150 mi.

A charge of 1.8 cents per bbl. is made for all water taken from the leases and returned to the Woodbine sand. At this rate a charge of 90 cents would be made for handling 50 bbl. of water.

The operator is allowed to produce one additional barrel of oil, worth $1.25, for each 50 bbl. of water injected for his account. This additional bonus oil is sufficient to pay for the salt water handling charge, the royalty interest and the cost of producing the oil. Thus the operator is able properly to dispose of the salt water produced from his lease without cost, but with considerable benefit to the field as a whole.

Oil and Salt Water Production

During the first five months of 1944, an average of 407,522 bbl. of water per day were produced from the field, during which time the oil production averaged only 368,796 bbl. per day. It is apparent, therefore, that more water is being produced than oil and since the reservoir pressure declines at approximately the same rate for water production as for oil production, it is highly important that the water be returned to the reservoir so that the pressure can be maintained.

In Table 2, the volume of salt water produced and the volume returned to the reservoir through injection wells is shown by months from October 1942 through September 1944. It will be observed that 81 per cent of all the water produced is now returned to the reservoir.

ILLINOIS OIL FIELDS—*Samuel F. Peterson*

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A contribution to the Journal

SALT water has always been an enigma to the oil operator. In water drive pools it is axiomatic that as oil production dwindles the volume of salt water increases. Its occurrence is not widespread but is localized, the first appearance usually being in edge wells which are located at low points on the structure. Due to this localization and the slow migratory progression over the structure, salt water disposal has long been considered an individual problem of the operator so affected, and not as a problem concerning all operators in the pool. Were salt water to appear simultaneously throughout the pool the problem would more than likely receive the co-operative attention of all the operators.

It is evident that if withdrawal of oil and salt water from a producing formation amounts to a considerable volume, the salt water withdrawn should be returned to the producing stratum to offset in part this displacement of volume. The return of salt water will augment the depleted reservoir pressure and wash the residual oil from the stratum, forcing it up the structural dip where it will accumulate at the well bores. Usually, by the time the limits of an oil pool have been defined, there are a number of edge wells ready for abandonment. Instead of plugging these wells, the operators, on a co-operative basis, should make arrangements to leave the casings in the wells and reserve them for future salt water disposal into the producing stratum.

When salt water first makes its appearance, the operator constructs pits to contain it, hoping it will evaporate

TABLE 1

Plant Location	*Source of Supply*	*Plant Location*	*Source of Supply*
Carmi	Little Wabash	Vandalia State Farm	Kaskaskia
Albion	Baupas Creek	Clay City	Little Wabash
Centralia	Lake Centralia, Raccoon Creek	Louisville	Little Wabash
		Mt. Vernon	Casey Fork
Flora	Little Wabash	Salem	Pipeline to Kaskaskia, 19 mi.; auxiliary source
Olney	Fox River		
Vandalia	Kaskaskia		
Mt. Carmel	Wabash	Murphysboro	Big Muddy
New Athens	Kaskaskia	Newton	Embarrass Creek
Fairfield	Little Wabash	Mascoutah	Silver Creek
Carlyle	Kaskaskia	Freeburg	Silver Creek
Zeigler	Big Muddy	Pinckneyville	Beaucoup Creek
Royalton	Big Muddy	Benton	Big Muddy Creek
Evansville	Kaskaskia		

or that he may drain it into nearby streams during flood stage. In Illinois the evaporation index is so low as to be practically negligible so far as being an aid in keeping ahead of salt water accumulation. Cultivated land is usually present in or adjacent to oil pools, so that crop and livestock damage is unavoidable and somewhat expensive to the operator.

There are 24 critical areas of public water supplies in the Illinois Basin under the supervision of the State Sanitary Water Board. In 1941 an act was passed by the Illinois state legislature delegating the set responsibilities of the board to the Department of Mines and Minerals, who have assumed the corrective measures in relation to salt water pollution when it has been called to their attention.

The plant locations and sources of water supply are given in Table 1.

Many industrial plants utilizing these streams for boiler water supply have experienced considerable difficulty in the past due to salt water pollution. It is estimated that in excess of 95 per cent of all salt water violations occurring in Illinois oil pools are due to seepage through and overflow of embankments.

As the volume of salt water increases beyond pit capacity, the operator is forced to drill a salt water disposal well or convert a depleted oil well to a disposal well. In the majority of cases, the salt water is returned to a non-producing or barren formation of a porosity sufficiently high to accomodate a large volume. Operators almost invariably have selected shallow barren sands above the producing formation in which to dispose of salt water. When pressure has been applied, the salt water in a number of instances has broken out in poorly plugged wells or has come to the surface around the outside of the casing in wells where the casing has not been cemented above the disposal formation. Should the amount of salt water not exceed several hundred barrels daily, the disposal formation can usually absorb the water by gravity. When, however, the volume to be injected approaches a thousand or more barrels a day, pumps must be installed and the salt water forced into the formation at high pressures. Almost all of these disposal operations are carried on individually by the operators in the pool.

Since the Division of Oil and Gas Conservation came into existence in

July 1941, 126 permits have been issued for salt water disposal wells. Of this number only seventeen permits have been issued to inject salt water into the producing oil formation. (Permits for water-flood wells are not included in this number.)

When one considers the large amounts of money spent by individual operators for salt water pits, settling basins, filtering systems, disposal wells, crop and livestock damages and stream pollution, the expense of co-operative effort should be amply justified. An ideal plan would be to unitize the entire pool for a water-flood project under the supervision of an Operators Advisory Committee. Either a unitized project or a co-operative program will eliminate the unnecessary duplication of pits, settling basins, filtering systems, compressors, tanks and disposal wells throughout the pool.

An unusual opportunity presents itself for some agency, such as the Illinois Petroleum Association, to encourage co-operative action for a two-fold purpose:

(1) To dispose of salt water into a common source, namely the producing stratum.
(2) To utilize salt water as an agent to recover the maximum ultimate yield of oil in the reservoir.

Problems will arise in invoking a co-operative program. Studies should be made of cores and cuttings to determine porosity, permeability, saturation point and lensing characteristics of the producing formation to be flooded, as well as the subsurface geological conditions. Haphazard trial and error methods and uncontrolled floods should give way to the scientific approach and controlled floods. Prejudices among operators and landowners around the perimeter of the pool must be dispelled. Valid objections offered by them must be met and compensated equitably. For instance, edge well operators and landowners may object to the disposal of salt water in the producing formation. They may contend that the oil on their lease will bypass their wells before they can recover their just share of the oil. These edge well operators and landowners could be paid a minimum rate per barrel for salt water disposed, when their abandoned wells are used, to compensate them for casing, possible loss of oil and use of surface area required for salt water disposal purposes. An equitable plan could be formulated and disposal details handled by an Operators Engineering Committee to make the plan practical.

There seems to be an unwillingness among many operators to introduce water into a producing formation before the entire pool is ready for abandonment—an unwillingness which is often unjustified. For example, many operators will have wells in a pool no longer profitable to operate, and they are receptive to flooding the oil stratum. However, a few operators in the pool may have profitable wells on their leases and they look upon any flooding efforts by individual operators with considerable distrust and are in a position to block such disposal efforts. As time goes on, this problem will become more and more acute in Illinois.

Summary

1. The history of salt water disposal in Illinois indicates that very little co-operative effort has been made

in water drive pools to dispose of salt water into the producing strata by means of edge wells, before such wells are abandoned and plugged.

2. In dissolved gas drive pools, little or no effort is being made to utilize salt water by perforating the upper strata in depleted edge wells and permitting the salt water to flood the lower producing stratum.

3. Up to the present time such disposal has been initiated almost entirely through individual efforts in the pool and such disposals are usually made into barren formations.

4. Both types of pools require cooperative programs, where lease ownerships are extensively diversified, in order to utilize salt water for augmenting reservoir energy and to flood the deeper producing strata either by gravity or under pressure.

5. A real opportunity presents itself for some oil association to devote its time and attention to studying the problem and encouraging such co-operative efforts for salt water disposal and flood, thereby recovering residual oil, unobtainable by the usual primary pumping methods.

The WPB's "Summary of Policies" of May 10, 1945

The following items are of interest to water works executives:

CMP Open-Ended—The Controlled Materials Plan will be open-ended effective July 1, 1945, so as to permit the delivery after that date, without CMP allotments, of steel, copper and aluminum, where delivery can be made without interference with authorized CMP orders. In other words, orders may be placed immediately for deliveries to be made after July 1, 1945. During the remainder of the second quarter, however, deliveries can be made only on authorized CMP orders and permission to place an unrated order does not guarantee delivery of that order.

Preference Ratings—The present rating system, the emergency AAA Preference Rating and individual directives will continue for the third quarter, 1945. The WPB Field Offices will be given authority to give "spot" ratings and assistance with a greater latitude than is presently authorized.

Construction Controls—The construction control order L-41 will be retained but will be progressively relaxed as resources become available in order to permit approval of projects that contribute to large-scale future employment and to satisfy other highly essential needs.

Availability of Resources—Resources of materials, manpower and facilities will become available only as military contracts are actually "cut back."

A number of materials are now, and are expected to continue to be, in short supply. Among these, for example, are containers, pulp and paper, many chemicals, lead, rubber, etc. Until the "cutbacks" begin to have substantial effect, other materials and products may remain in short supply. Metals, for example, will probably remain short for two or three months, while sheet steel may remain tight somewhat longer. Also it must be understood that the release of a WPB control or the lifting of a WPB order does not mean that every material required by a product will be available.

Controls of Other War Agencies—Removal of particular WPB controls in no way affects the continuing controls of other war agencies. In resuming or expanding civilian production, manufacturers remain subject to all applicable regulations of the Office of Price Administration, the War Manpower Commission and other federal war agencies.

Impounding Reservoirs for Salt Water Disposal

By M. F. Granville

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Presented on Oct. 19, 1944, at the Southwest Section Meeting, Austin, Tex.

AT the present time there are three methods of disposing of salt water: controlled dilution in surface streams; injection in subsurface formation; and extraction of the salts. This discussion will be limited to the first process only: that is, controlled dilution in surface streams.

This method of disposal can be effective only when there is sufficient water to dilute the brine to the proper extent without at the same time affecting the quality of the stream water. Hence the proper planning and construction of reservoirs is essential.

Even before construction is begun, surveys should be made of the normal flows of the streams into which the impounded water is to be released. Also, studies should be made of normal rainfall over the territory or watershed furnishing water to these streams, and probable increases in salt water production should be estimated. These considerations will largely govern the size and number of impounding reservoirs to be constructed.

Such reservoirs should be designed and constructed by an engineer familiar with soil dynamics, so that after they are built the salt water will not seep out through levees nor find its way into the subsurface formations through the bottom of the reservoir. They should be constructed of concrete if possible, or be lined by the gunite process. Experience with reservoirs constructed out of available local soils proves that while they will serve in an emergency, or for about three or four years, after that time they deteriorate rapidly and begin to allow seepage.

These impounding reservoirs should also be equipped with proper outlet pipes and gages. The outlet pipe should be leak-proof and fitted with a good valve, and should be laid to the nearest creek or branch, so that no salt water from the reservoir can spread over the surface near the pit and kill vegetation, nor get into subsurface formations and affect domestic water supplies. Adequate gage facilities should be provided so that the amounts of water stored or released can be readily ascertained at any time.

Controlled Dilution

In the event that there are no rivers or streams having sufficient flow at or near these reservoirs, into which brine may be released gradually, the following plan may be interesting. It was devised by the Salt Water Control Committee in 1940, and is now operating in that part of the East Texas oil field known as the Angelina-Neches River watershed.

This plan for the disposal of salt water is the result of a suit brought by the state of Texas against some 158 oil operators on the Angelina-Neches

River watershed for polluting the waters of the Neches River. During the trial of the case (*State of Texas* vs. *Acme Gas & Oil Company, Ltd., et al.*, Cause No. 53,113-F, 116th District Court, Dallas County, Texas) an agreement was reached between the Attorney General's office and the operators as to a workable plan for disposing of salt water. When this happened the Court postponed hearing the case. The agreement became known as the Postponement Agreement, and is the authority under which the Salt Water Control Committee operates.

The committee, composed of the heads of the Texas State Department of Health, State Board of Water Engineers, Attorney General's Department and the Game, Fish and Oyster Commission, drew up a set of rules and regulations designed to protect vegetation and water supply in areas adjoining reservoirs. Specifications were given for pit construction of the impervious type, pit gages and pit outlet pipes to be laid to the nearest creek. Sampling stations were installed at seven points on Bowles Creek, the stream on which this part of the oil field is located, and 21 samples are taken and analyzed daily.

In addition to these stations there is a gaging and sampling station on the Neches River between Jacksonville and Neches; one at Striker Creek (a continuation of Bowles Creek) between Henderson and Jacksonville; and one at Evadale below the junction of the Angelina and Neches rivers. At each of these stations samples are taken and gage readings made daily. In addition to the foregoing stations the committee has daily water analyses from the lower Neches Valley Authority and the city of Beaumont laboratory, both at Beaumont.

Under the foregoing arrangements the Committee on Salt Water Control is well informed at all times regarding the condition of the Neches River and its tributaries. The rainfall area used in computing water for dilution purposes is 1,261 sq.mi. Rainfall is reported by the rainfall stations at Tyler, Henderson, Jacksonville and Nacogdoches and when it is sufficient to permit the release of salt water the committee issues a release order. Water is released from storage in the field only at such times and in such quantities as will not lead to a salt content higher than 700 ppm. chloride on the Angelina River.

The committee is further provided with weekly reports of the amount of salt water in storage by means of cards mailed by the operator to the field office. A patrol is maintained to note and enforce the proper handling of salt water. All pit outlet valves are sealed and these seals must not be broken until a release order is given.

From the foregoing remarks it is evident that for effective long-time use impounding reservoirs for salt water disposal should be constructed of concrete or gunite. In the East Texas oil field there does not remain a single salt water pit, which has been constructed of local soils in the last four years or more, that does not allow water to seep through the levee or the bottom of the pit.

Control of Salt Water Intrusion in Texas

By A. M. Brenneke

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Presented on Oct. 19, 1944, at the Southwest Section Meeting, Austin, Tex.

THE problem of salt water intrusion is more far-reaching in scope than most people realize. Salt water can, and does, damage many sources of fresh water. It can retard industrial development, damage large areas where irrigation is of prime importance to the economy of the state and its citizens, ruin municipal water supplies and kill fresh water fish.

Samples taken from the major rivers of Texas at many points and over a period of years show that every major river in the state is contaminated with salt water to some extent throughout one or more sections of its length.

The analyses also show that on some streams the concentration has been increasing, while on others, notably the Sabine and the Neches, after having risen to alarming proportions, the concentration has been decreasing.

The accompanying map of Texas indicates the watersheds of the major river systems and the more than 500 oil fields of the state. These oil fields are the sources of most of the salt water in the streams. Certain areas in West Texas, Oklahoma and New Mexico, however, are known to have surface soils which contain chlorides and sulfates. The contamination from these sources is natural contamination and it is extremely doubtful that a means can be found to prevent the rainfall from bringing these chlorides and sulfates in solution into the streams.

However, when salt water finds its way from oil fields into the streams and underground fresh waters, the contamination is man-made and, therefore, can be prevented.

A study of salt water intrusion, made by the author during the past several months, has revealed the following facts.

Prior to any control of salt water from the East Texas oil field the municipal water supply of Beaumont was critically contaminated.

Because of the contamination on the Sabine River by oil field salt water, in 1936 the city of Longview was forced to expend over $400,000 to secure a new surface supply. Subsequently, oil was found and is now being produced in three separate areas on the new watershed. One of these areas is producing considerable salt water but, fortunately, the producers are controlling it and, so far as is known, none is being released where it can find its way into the supply. The question arises: Will the city of Longview be forced again to expend several hundred thousand dollars for a *third* water supply?

For many years the city of Graham used Salt Creek, a tributary of the Brazos, as its source of water supply. In spite of its name, the water was fresh and good at the plant intake.

Map of Texas Showing Major River System Watersheds and Oil Fields

In 1929 Graham was forced to abandon this supply because of oil field salt water contamination. A new supply was secured upstream on a tributary which had adequate runoff and which was in an area with no oil development. There are now about 130 oil wells on the new watershed, most of which are producing salt water. A few wells are on the watershed just at the head of the reservoir and salt water from these is supposed to be ditched through the divide away from the watershed. The only other known attempt to control salt water is by placing it in surface pits, where evaporation removes some of the water but none of the salt. What is retained is released during periods of good flow in the streams. In practice this method has not proven satisfactory and is most undependable. As a result, the chloride content of Graham's reservoir has risen from 0 ppm. when new to about 38 ppm. in the summer of 1940. This is not yet serious, but will it be? Will the city of Graham be forced again to expend a large sum of the taxpayers' money for a third water supply?

A few years ago the source of supply for the city of Lockhart was a shallow stratum of underground water south of the city. On the upper reaches an oil field was developed and pits were dug for the storage of the salt water. These pits penetrated the water-bearing gravel bed and caused rapid and direct contamination of the supply.

Little is now known of the degree of infiltration or intrusion of salt water into the lower water-bearing sands. The time required for infiltration at the surface to reach a well some miles away is, possibly, many years. It therefore follows that a high salt water intrusion would require years to become noticeable—and just as many years to be cleared up.

Numerous reports have been received regarding the salt water contamination of shallow wells in and near oil fields. This is a condition that still exists in many oil fields.

In the use of water for irrigation, the Rio Grande Valley, the Pecos Valley and the Gulf Coast area east of Houston are probably the most important to the state. The rice growers around Beaumont and Orange were, and are still, concerned about the chloride content of the water they use for irrigation. At present, chlorides are low enough for satisfactory use in the lower reaches of both the Sabine and the Neches. This is due to the control of the salt water from the East Texas oil field (however imperfect this control is known to be) plus dilution from the tributaries below the oil field.

On the Rio Grande, samples taken in 1944 showed chlorides as high as 800 ppm. This is too close to the limit of tolerance reported for many crops grown in this area and is too high for satisfactory municipal use.

On the Pecos, near Girvin, chloride contents ranging from 3,000 ppm. to 5,050 ppm. were found in the 108 samples taken between April and August 1943. The Pecos is one of the rivers which carry considerable contamination, but it also carries drainage from oil fields. Samples taken from small creeks below oil fields showed chlorides present varying between 25,000 and 46,000 ppm. These creeks are on the Pecos watershed and add to the natural contamination.

There has been considerable discussion recently regarding the industrial development of the state—about large firms erecting huge plants for process-

ing some of the resources of the state, either agricultural or mineral; and about the reconversion of existing war facilities to peacetime pursuits. The quantity of water any such large industrial plant needs does not seem to have been considered. To illustrate, the Southland Paper Mills near Lufkin report they use 10.0 mgd. and then reuse 1.5 mgd. of this. It is also reported that the Dow Chemical Co. plants near Freeport anticipate a water requirement of 100 mgd. In addition to the huge quantities needed, there are minimum standards of quality to be met for the successful operation of an industrial plant, and almost without exception the chloride content must be much lower than that for a municipal supply.

The Game, Fish and Oyster Commission has been most active in efforts to maintain the chloride content of the streams within safe limits for fresh water fish. The term "safe limits" varies for several species of fish common to Texas streams and more experimental work is necessary before the proper limits can be determined. The work that has been done indicates that chlorides to the extent of about 2,000 ppm. are probably too high for some fresh water fish in Texas, but are not too high for others.

Briefly, the foregoing are the conditions which exist. The controls which are being practiced in the East Texas oil field are admittedly not too good and depend largely on the individual producer.

What, then, is the solution to the problem? Only three possibilities appear to have any merit: (1) keep the salt water out; (2) dilute the salt water with fresh water; or (3) use a combination of these.

An existing state law prohibits contaminating a water course to a degree detrimental to any of the normal uses of the stream or its waters. Taking into consideration the present needs of the waters in the Angelina and Neches rivers and the diluting flow from tributaries, state enforcement agencies have set 2,000 ppm. as the chloride limit below the East Texas oil field. This limit is satisfactory so long as no use is made of the stream that will require a water of higher quality within the distance downstream from the point of contamination as may be needed to permit the entrance of sufficient dilution water to lower the chloride content to the desired point. In some rare cases this may be but a few miles; in others it will probably be around 100 mi. For example, the Sabine at Logansport is not very satisfactory for municipal use many miles below the point of contamination. In still other cases a stream may be ruined for nearly its entire length, particularly if a chloride content below 35 or 40 ppm. is required.

The law also provides a penalty for violation—a fine of not less than $100 nor more than $200—and permits the issuance of an injunction to prevent a recurrence of the offense. The fine does not seem to have been effective in stopping the dumping of salt water. It appears to have worked on the order of fining a theater operator $20 for opening on Sunday. The fine was paid but the theater continued to open on Sunday. The operator merely made $20 less that day than he would have made otherwise.

Court proceedings through injunction are a real threat to an oil producer who violates the law, but it is such a slow cumbersome process that many

who are familiar with conditions are of the opinion that there is need for revision of the existing law and its enforcement provisions. It appears to the author much more desirable to prevent contamination than to try to correct it after it has happened.

Suggestions and Recommendations

The following suggestions are offered as means of controlling salt water in Texas:

1. By statute, create a Salt Water Control Commission, composed of the state health officer, the chairman of the Board of Water Engineers and the chairman of the Game, Fish and Oyster Commission. The commission should be instructed to employ a qualified registered professional engineer as executive, together with an adequate staff to gather data, to care for the operation of the office and to prepare cases against violators of the law.

2. By statute, instruct the Railroad Commission to shut down any well in any oil-producing area within five days of the receipt of a certificate from the Salt Water Control Commission that salt water from any certain well or group of wells is being permitted to enter a water course or a fresh water-bearing stratum of underground water to an extent that is detrimental. Such a well or group of wells should be required to remain closed down until the Salt Water Control Commission has certified to the Railroad Commission that the producer has made arrangements for the disposal of salt water that are satisfactory to the Salt Water Control Commission. Instruct the Railroad Commission that no oil from such well or wells so shut down is to be accepted in commerce during the period of the shut-down.

Require the issuance of a drilling permit by the Railroad Commission prior to the drilling of any well for oil or gas, and require that such permit shall not be issued until the receipt of a certificate by the Salt Water Control Commission that the operator has filed plans for the control and disposal of all oil well wastes and that such plans have been approved by the Salt Water Control Commission.

3. Authorize the Salt Water Control Commission to prescribe such regulations as may be deemed necessary for the enforcement of the law, and to require the submission and prior approval of all proposed methods of salt water disposal contemplated by all producers. Require that no well shall be drilled for oil without first obtaining a drilling permit as stated in Par. 2 above, and fix a heavy penalty for violation of this requirement.

4. Assess a charge of one cent per 100 barrels of oil produced against each producer, to be paid by the first purchaser of oil from the well and paid monthly to the state rather than to the producer. This fund will be for the exclusive use of the commission in salt water control and enforcement.

5. Repeal all conflicting sections of the existing law.

The cost of operating such an agency is estimated to be about $75,000 for the first year and about $70,000 per year thereafter. One cent per 100 barrels of oil produced is adequate. The state of Kansas charges four cents per 100 barrels of oil for the supervision of salt water disposal.

It is realized this is but one of several ways to finance the proposed commission. Financing could be by legislative appropriation, but it is believed the cost should be borne by the oil

producers rather than by the taxpayers. It is believed that an assessed charge should be based on the quantity of salt water produced, rather than against the quantity of oil produced. However, simplification seems to indicate the proposed method is easiest and cheapest, and it is of minor significance to a producer whether the assessement be against oil produced or against salt water produced.

It should be noted that all the so-called major companies and a great number of smaller producers are fully cognizant of conditions and are sparing no effort to keep salt water contamination of fresh waters within safe limits.

It is believed that these proposed changes in the present law will tend to eliminate violations of the law, will promote a fuller understanding of the responsibilities of the producers and of the several state agencies now concerned, will result in a greatly improved stream condition and, at the same time, will work no hardship on any oil producer who is trying to protect the fresh waters of the state.

Another solution to this problem would be to devise some system whereby it would be to the advantage of each oil producer to take proper care of his salt water. A solution along these lines appears doubtful, however, for even though satisfactory in principle, some control would be necessary to determine what constitutes satisfactory disposal. Experience for many years has shown that this cannot be left to the individual producer. Quite possibly the best solution would be a combination of these two methods, that is, close supervision with a charge for the cost of supervision and a credit for good control, possibly in the way of some additional allowable oil production to offset the cost of supervision.

Readers are referred to a report entitled "Application of Sand Filters to Oil Field Brine Disposal Systems" by Samuel S. Taylor and L. F. Christianson, published by the Bureau of Mines, U.S. Department of Interior, Bulletin R.I. 3334, January 1937.

1944 Census of U.S. Municipal Water Softening Plants

By H. M. Olson

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A contribution to the Journal

IN the December 1941 "Census of U.S. Municipal Water Softening Plants" [Jour. A.W.W.A., **33**: 2153 (1941)] a tabulation was made of all plants listed at that time, with important data relative to each.

In assembling the information shown in that census, the list of plants was compiled from the records of the various state departments of health, consulting engineers and manufacturers' representatives, and from private information in the possession of the author. A questionnaire was sent to each plant thus listed.

All but twelve plants replied. It was felt that the tabulation was very nearly complete because the data were checked by the various state health departments who supervise all municipal plant operations. In compiling an additional list as of Jan. 1, 1945, however, it was found that some plants which were operating prior to Sept. 1, 1941, were actually in operation as water softening units. Some of the plants now shown under "New Plants Listed Since December 1941" were no doubt under construction late in 1941 but were not as yet subject to the operational jurisdiction of the state health departments, and were therefore not listed in the previous census.

The data compiled by the U.S. Public Health Service and published in the Jan. 27, 1943, issue of *Water Works Engineering* (**96**: 63) entitled, "Water Treatment Plants in U.S.," were used as a basis in assembling the information concerning additional plants as of Jan. 1, 1945. The names of plants were sent to the various state health departments for a check on accuracy and for possible additions. With the revised list a questionnaire was sent out requesting information regarding the type of softening, whether zeolite or chemical precipitation, and the year in which softening operations were started.

Replies were received from about 80 per cent of the 117 questionnaires. Surprisingly enough, several plants reported that they do not soften their water supply and they are therefore not included in the listings. It was found that 108 new softening plants are now in operation, which, with the nineteen from the previous census now not operating, left a gain of 89 plants.

The plants from which no answers were received are listed as to type of plant as shown in the U.S.P.H.S. Survey, and, since most of the names were shown in the 1942 Addenda of the survey, 1942 is used as the year in which those plants went into operation.

In the listings to follow several plants, notably in Indiana, Minnesota and Wisconsin, are shown on which construction was begun in 1945. Although these plants are not yet in operation, they will be in about a month or two, and are therefore included.

The accompanying figure shows the growth of municipal softening in the United States from 1905 to 1945.

The following states show no record of municipal water softening plants and are therefore not included in the tabulation below: Connecticut, Idaho, Maine, New Hampshire, Oregon, Rhode Island, Utah, Vermont and Wyoming.

The division of softening plants by areas is shown in Table 1.

The tabulation below shows the percentages of chemical precipitation and zeolite plants as of December 1941 and January 1945:

	December 1941		*January 1945*	
Type of Plant	*No. of Plants*	*Percentage of Total*	*No. of Plants*	*Percentage of Total*
Chemical Precipitation	377	65.5	427	64.2
Zeolite	199*	34.5	238*	35.8
TOTAL	576	100.0	665	100.0

* Including two chemical-zeolite plants.

Table 2 is a summary of the estimated total population served by water softening plants as of Jan. 1, 1945.

The division of plants by size of population served is:

	December 1941	*January 1945*	*Gain*
Under 1,000	147	194	47
1,000 to 5,000	240	272	32
5,000 to 10,000	79	88	9
10,000 to 20,000	56	55	−1
20,000 to 50,000	31	32	1
50,000 to 1,000,000	22	23	1
Over 1,000,000	1	1	0
TOTAL	576	665	89

The biggest gains were made in the smaller communities with populations under 5,000, which would indicate that the smaller communities have become aware of the savings that can be effected with softened water supplies.

From the above data it will be noted that the relationship between the number of zeolite and chemical precipitation plants has remained essentially the same as in December 1941.

Although most of the additional plants were installed in the lower population group, it is expected that in the postwar period of construction many cities in the larger population group

TABLE 1

	Dec. 1, 1941	*Jan. 1, 1945*	*Gain*
New England States (Massachusetts)	1	2	1
Northeastern States (Delaware, Maryland, New Jersey, New York and Pennsylvania)	57	66	9
Central States (Illinois, Indiana, Michigan, Ohio and Wisconsin)	250	275	25
Southeastern States, East of Mississippi River (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia and West Virginia)	71	84	13
Western States (California, Nevada and Washington)	12	14	2
Rest of States West of Mississippi (Arizona, Arkansas, Colorado, Iowa, Kansas, Louisiana, Minnesota, Missouri, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota and Texas)	185	224	39
TOTAL	576	665	89

TABLE 2

Estimate of Population Served by Water Softening Plants
January 1, 1945

Estimated population served, Dec. 1, 1941	9,912,075
Estimated population in additional 108 plants listed as of Jan. 1, 1945 (based on 1940 census) [1]	548,462
TOTAL	10,460,537
Less: Estimated total population of 19 plants no longer operating	309,521 [2]
TOTAL	10,151,016
Increase in population of the United States as of Jan. 1, 1945, is approximately 7,500,000.[3] Approximately 5.72 per cent increase covering total of figures noted above	580,637
TOTAL	10,731,653
Ten per cent increase in urban population due to war conditions and other shifts of population (*approximate*)	1,073,165
GRAND TOTAL POPULATION SERVED BY WATER SOFTENING PLANTS	11,804,230

[1] This figure does not take into consideration any additional communities that may now be served by the plants listed in the December 1941 census or in the January 1945 listing.

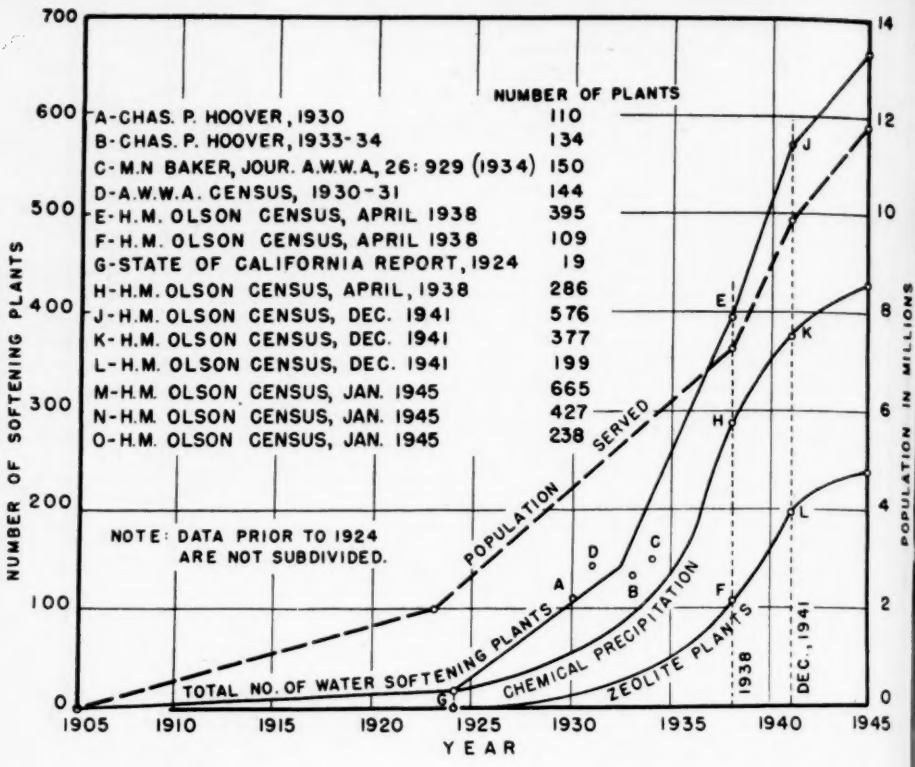
[2] Large drop in population due to city of Grand Rapids, Mich., with a population of over 164,000, and Wichita Falls, Tex., over 45,000.

[3] This does not take into consideration the armed forces population of between 6,000,000 and 7,000,000 now out of the country.

will install water softening plants. Such cities as Freeport, Ill., Davenport, Iowa, Louisville, Ky., Dayton, Ohio, Des Moines, Iowa, and Springfield, Ohio, have either indicated that they will go ahead or have already retained consulting engineers to draw up designs, plans and specifications. It is estimated that there will be well over 1,000 municipal water softening plants by Jan. 1, 1950, which will be about a 50 per cent gain over the number now installed, or about 355 plants at the rate of from 65 to 70 plants per year. Even such plants as Chicago's South Side Filtration Plant, which is so designed that it can be converted at small cost to a softening plant, may be in operation as a softening plant by Jan. 1, 1950, or soon thereafter. The same is true for Milwaukee, Wis., Cincinnati, Ohio, and other plants.

The fast growth of the soft water service system is another factor to be taken into consideration in softening water for municipal uses. The first of these was started in Rockford, Ill., in 1937 and later at Wheaton, Ill., and Hagerstown, Md., in 1938. These plants operate from 90,000 to 110,000 units with 2,600,000 regenerations annually, supplying into homes or commercial plants a water softened from 15 grains average hardness to zero hardness. The approximate population thus served will be around 350,000 to 375,000. Each unit contains about 1.6 cu.ft. of synthetic gel-type zeolite. Special zeolites are used where iron and manganese are present. Where hydrogen sulfide is present a special zeolite with an activated carbon admixture is used for taste removal.

These soft water units are now in use at approximately 200 central service plants serving 310 communities. Most of the service plants are operated by private firms, although twelve or



fifteen municipalities are now offering this service to their consumers.

In addition to the conventional domestic zeolite softener which has been in use for many years and which is usually installed, owned and operated by the consumer, there are two types of soft water service equipment. One, a steel pressure shell, is filled with zeolite that is connected into the service by a set of bypass valves. This shell is replaced with a similar unit when the zeolite has been exhausted. The exhausted unit is then taken to a central regeneration plant where multiple sets of units may be backwashed, regenerated, sterilized and made ready for use again when required.

The other system consists of a steel pressure tank with a hinged top into which are placed four bags of zeolite. When exhausted, the bags are removed and the contents replaced with active zeolite mineral. The exhausted zeolite mineral is removed to a central plant where it is dumped, backwashed and regenerated and a small chlorine sterilizing pellet inserted in the softener unit. A monthly service charge is made depending on the water hardness and the number of regenerations.

Table 3 lists the new installations made since the December 1941 census. Also listed are those plants included in the December 1941 census which have for one reason or another been discontinued as water softening plants.

Table 4 shows the number of water softening plants divided into types for December 1941 and January 1945.

TABLE 3

Water Softening Plants Installed and Discontinued Since December 1941

New Plants Listed Since December 1941				Plants No Longer in Operation	
State	City	Year Installed	Type Plant	City	Type Plant
California	Hawthorne	1941	C		
Florida	Holly Hill	1942	C		
	New Smyrna Beach	1941	Z		
Illinois	Blue Mounds	1942	Z	Kincaid	C
	Camp Point	1942	Z		
	Chatsworth	1942	Z		
	Crossville	1941	Z		
	Mt. Auburn	1942	Z		
	Niantic	1942	Z		
	Mackinaw	1942	Z		
	Prairie du Rocher	1940	Z		
	Teutopolis	1942	C		
	Warrensburg	1941	Z		
	Salem	1942	C		
	Sparta	1945	Z		
Indiana	Lawrenceburg	1942	Z	Elnora	C
	Edwardsport	1928	Z		
	Greendale	1945	Z		
	Greensburg	1945	C		
Iowa	Hedrick	1941	Z		
	Alden	1940	C		
	Corwith	1941	Z		
	Elk Horn	1942	Z		
	Mediaopolis	1942	Z		
	Modale	1941	Z		
	Redfield	1941	Z		
	Swea City	1942	Z		
	West Burlington	1939	C		
	Woodward		C		
	Carson	1941	Z		
	Winfield	1941	Z		
Kansas	Strong	1937	C	Council Grove	C
	Emporia	1937	C	Eldorado	C
	Ottawa	1939	C		
	Marion	1942	C		
	Eudora	1942	C		
	Wichita	1940	C		
	Fort Scott	1942	C		
	Elwood		C		

TABLE 3—*Continued*

New Plants Listed Since December 1941				Plants No Longer in Operation	
State	City	Year Installed	Type Plant	City	Type Plant
Kentucky	Clay	1942	Z	Dixon	C
	Glomawr	1940	Z	Jenkins	C
	Kentucky Dam	1939	C	McRoberts	C
				Sturgis	C
				Wheelwright	C
Louisiana	Geismar		C	La Fayette	C
	Jennings	1941	C	Monroe	C
	Gramercy	1943	C	Patterson	C
	Houma	1942	C	St. Martinsville	C
	Marrero	1942	C		
	Rayville	1942	C		
	Tallieu	1942	C		
	Weeks Island	1942	C		
	New Iberia		C		
Massachusetts	Lanesboro	1941	Z		
Michigan	Ramsay	1942	C	Anvil Location	C
				Grand Rapids	C
Minnesota	Chisholm	1938	C		
	Le Roy	1945	C		
Missouri	Princeton	1942	C		
	Maryville	1942	C		
	Hayti	1942	C		
	Carrollton	1942	Z		
	St. Charles	1942	C		
	Slater	1942	C		
	Tarkio	1941	C		
	Wellington	1942	C		
Montana	Columbus	1941	Z		
Nebraska	Stromsburg	1942	C		
	Syracuse	1942	Z		
Nevada	Reno	1942	C		
New Jersey	Holland Township		Z		
New York	Wappingers Falls	1941	Z		
	Latham Water District		Z		
North Carolina	Washington	1944	Z	Valdese	Z
North Dakota	Cooperstown	1941	C		

TABLE 3—*Continued*

New Plants Listed Since December 1941				Plants No Longer in Operation	
State	City	Year Installed	Type Plant	City	Type Plant
Ohio	Chauncey	1942	C	McDonald	C
	Hilliards	1942	C		
	Mt. Orab	1942	C		
	Nelsonville	1941	C		
	Rushsylvania	1942	C		
	Somerset	1942	C		
	Sycamore	1942	C		
Oklahoma	Okemah	1942	C		
Pennsylvania	Aliquippa	1942	Z		
	Alicia		C		
	Aurora Village		C		
	Vandergrift	1942	C		
	N. Versailles Township (McKeesport)	1942	C		
	Ross Township (Allegheny County)	1943	Z		
South Carolina	Bamberg	1942	Z	Orangeburg	C
South Dakota	Chamberlain	1942	C		
Texas	Austin		C	Wichita Falls	C
Tennessee	Jefferson City	1942	C		
Virginia	Shenandoah	1942	C		
West Virginia	Bradshaw	1938	Z		
	Elkhorn		C		
	Eckman	1934	Z		
	Glenalum	1942	C		
	Handley	1942	C		
	Landgraff	1942	C		
	Monaville	1942	C		
	Pageton	1942	C		
	Cameo	1938	Z		
	Upland		C		
	Vivian		C		
Wisconsin	Campbellsport	1942	Z		
	Omro	1943	Z		
	Appleton	1942	C		
	Chilton	1945	Z		
	Cambria	1945	Z		
	Markesan	1945	Z		

TABLE 4

Number of Water Softening Plants for December 1941 and January 1945, Showing Gain or Loss in Total Number of Plants

State	December 1941			January 1945			Gain or Loss in Total Plants
	Zeolite	Chemical Precipitation	Total	Zeolite	Chemical Precipitation	Total	
Alabama	4	0	4	4	0	4	0
Arizona	2	0	2	2	0	2	0
Arkansas	0	4	4	0	4	4	0
California	3+1 CZ*	6	10	3+1 CZ*	7	11	+ 1
Colorado	0	1	1	0	1	1	0
Delaware	0	1	1	0	1	1	0
Florida	3	20	23	4	21	25	+ 2
Georgia	1	3	4	1	3	4	0
Illinois	41+1 CZ*	34	76	49+1 CZ*	37	87	+11
Indiana	10	6	16	13	6	19	+ 3
Iowa	13	22	35	22	25	47	+12
Kansas	0	23	23	0	29	29	+ 6
Kentucky	1	8	9	3	4	7	− 2
Louisiana	3	23	26	3	28	31	+ 5
Maryland	2	0	2	2	0	2	0
Massachusetts	1	0	1	2	0	2	+ 1
Michigan	4	14	18	4	13	17	− 1
Minnesota	2	12	14	2	14	16	+ 2
Mississippi	1	1	2	1	1	2	0
Missouri	19	22	41	20	29	49	+ 8
Montana	0	2	2	1	2	3	+ 1
Nebraska	1	3	4	2	4	6	+ 2
Nevada	0	1	1	0	2	2	+ 1
New Jersey	1	0	1	2	0	2	+ 1
New Mexico	0	1	1	0	1	1	0
New York	12	0	12	14	0	14	+ 2
North Carolina	3	2	5	2	3	5	0
North Dakota	1	7	8	1	8	9	+ 1
Ohio	23	98	121	23	104	127	+ 6
Oklahoma	0	3	3	0	4	4	+ 1
Pennsylvania	14	27	41	16	31	47	+ 6
South Carolina	3	1	4	4	0	4	0
South Dakota	0	6	6	0	7	7	+ 1
Texas	5	10	15	5	10	15	0
Tennessee	0	0	0	0	1	1	+ 1
Virginia	7	2	9	7	3	10	+ 1
Washington	1	0	1	1	0	1	0
West Virginia	6	5	11	8	14	22	+11
Wisconsin	10	9	19	15	10	25	+ 6
TOTALS	199	377	576	238	427	665	89

* Combination Chemical Precipitation-Zeolite Plant.

Abstracts of Water Works Literature

Key: In the reference to the publication in which the abstracted article appears, **34:** 412 (Mar. '42) indicates volume 34, page 412, issue dated March 1942. If the publication is paged by the issue, **34:** 3: 56 (Mar. '42) indicates volume 34, number 3, page 56, issue dated March 1942. Initials following an abstract indicate reproduction, by permission, from periodicals, as follows: *B.H.—Bulletin of Hygiene (British); C.A.—Chemical Abstracts; P.H.E.A.—Public Health Engineering Abstracts; W.P.R.—Water Pollution Research (British); I.M.—Institute of Metals (British).*

FLOODS, HURRICANES AND EARTHQUAKES

Effect of the 1944 Hurricane on Water Supplies in Massachusetts. FRANCIS H. KINGSBURY. J.N.E.W.W.A. **59**: 1:13 (Mar. '45). On morning of Sept. 14 dist. san. engrs. of Mass. Dept. of Public Health directed to stand by throughout day, to fuel all cars and to check equipment and supplies. System of water supply co-ordination, organized in '41 under State Emergency Plan, set in motion. Water supply officials throughout state notified of probable hurricane and directed to fill all standpipes and take such other precautions as they deemed necessary. Dept. kept informed of progress of hurricane by office of Adjutant General. At 11:15 P.M. on Sept. 15 reports received from Martha's Vineyard, Nantucket and Provincetown indicated that all public water supplies in operation and that no source of public water supply affected by flood waters, although 2 instances of damage to water mains. In all cases where pumping mchy. dependent on elec. power only, such power restored. In Cape Cod and Buzzards Bay areas, all water supplies had auxiliary motive power for pumping water or regular diesel engines. Installations of auxiliary power units at many pumping stations due in part to recommendations of dept. following '38 hurricane. Importance of interconnections between municipalities illustrated where water mains broken at Fairhaven and Hyannis. At Fairhaven water being obtained for section of town from Achushnet which is supplied with water from New Bedford. Break at Hyannis occurred in main from Hyannis to Hyannisport and Hyannisport supplied through connection with Centerville-Osterville Water Dist. until main could be repaired and disinfected. At Tisbury, dike near source of water supply overtopped several inches by salt water from Tashmoo Pond but did not result in poln. Some semi-public water supplies in village of Sagamore in Bourne without power for pumping water, but water supplied to residents by means of Army water trucks from Camp Edwards. Hurricane not as devastating as that of '38. Dist. san. officers contacted all local boards of health in southeastern Mass. to offer assistance relative to private water supplies or health hazards resulting from flooded bldgs. Mimeographed copies of instructions for disinfection of drinking water, inundated basements, etc., given to local health officials for distr. Dept. offered to assist local boards of health in analyzing samples of water from inundated wells. Of 82 private sources of supply examd. 46 found to contain chlorides in such amts. as would make water unsuitable for most domestic purposes and 29 found to contain water with large numbers of coliform organisms. Latter wells since disinfected, pumped out and rechecked as to chloride content. Procedure developed to det. in field chloride content or salinity of water in wells, as follows: Use clean glass-stoppered bottle of 8-oz. capac. Pour 50 ml. of sample into bottle and add 1 ml. of potassium chromate indicator soln. (50 g./l.). Add entire contents of one of amber glass ampoules which contain 2½ ml. silver nitrate soln. (48.9 g./l.). Shake vigorously for ½ min. If, at end of that time, and *while still shaking*, soln. appears anywhere from *faintly reddish* to *brick red* in color, chloride content *less* than 500 ppm. If soln. remains *lemon yellow* in color, chloride content *greater* than 500 ppm. and water would be unpalatable because of salty taste. Recent hurricane indicates that storms of this nature may be expected from time to time and emphasizes importance of auxiliary units for pumping water and interconnections between municipalities.—*Ed.*

Effect of the 1944 Hurricane on Rhode Island Water Supplies. WALTER J. SHEA. J.N.E.W.W.A. **59**: 1:19 (Mar. '45). Sept. 14, '44, hurricane caused far less damage to Rhode Island property than '38 hurricane. Combination of high tide and high wind which characterized '38 hurricane absent in latest storm. Consequently damage caused by flood waters relatively small. Loss of elec. power not widespread and every water util. in state had power from one source or another within few hours of end of storm. Only 2 water supplies in state affected seriously. (1) *Bristol Co. supply:* Forced to shut down and leave consumers of 3 towns without water for 2 days. Source of supply consists of 4 impounding reservoirs, 3 of which supply water to fourth or intake reservoir. Water from intake reservoir pumped to purif. plant and after treatment pumped into system. Low dam prevents sea water of tidal portion of Kickemuit R. from mixing with intake reservoir water under normal conditions. High water which accompanied storm, however, caused sea water to overflow dam. While elec. power to operate pumping equip. restored after brief interruption, to maint. water service would have been necessary to pump water of high salt content into system. Decided not to do this because (1) water could not be used for drinking, (2) it would have adverse effects on boilers and other uses, and (3) it would take some time to free system of it when fresh water became available. Instead, work started to install wooden flume 750′ long to connect pipe, which empties water from Shad Factory reservoir into upper end of Kickemuit reservoir, directly with pumping station intake and thus bypass salted reservoir. By working 24-hr. day flume completed in about 36 hr. Water service restored in 48 hr. During shut-down elevated storage tanks cut off to conserve their contents for fire protection purposes. When filtered water turned into mains again, heavy dose of chlorine applied to provide safeguard against contamn. that might have found its way into partially emptied piping system through either back-siphonage or leaks in system. Addnl. precaution taken of warning users to boil all drinking water drawn from system for period of 36 hr. after service restored. Residual chlorine tests showed that chlorine had become well distributed throughout system. (2) *Newport system:* Loss of power at Lawtons Valley plant made it necessary to use auxiliary source consisting of gasoline engines. Plant run on these engines for 3 days before usual source of power restored. Power lost at main pumping station for about 12 hr.; service maintd. without resorting to use of steam pumps. Nonquit Pond, one of sources of water, became salted by sea water flooding over low dam which separates pond from sea. Resulting mixt. contained from 1200 to 1500 ppm. chlorides. While salt content of pond reduced somewhat since storm, more rainfall will be needed to return pond to normal condition. Experience proves certain min. requirements must be met by water works systems to maint. uninterrupted service following hurricanes. Pumping stations should be so equipped that there will be no interruption in power of long enough duration to deplete finished water storage below safe limit. Water pumping stations and treatment plants located near sea, or near waterways where flooding may occur, require special provisions for emergencies. Source of raw water beyond reach of flooding sea water essential. At time of '38 hurricane, lack of such source at one plant prevented use of auxiliary steam pumps which could have made up for lack of power from usual source. Lack of fresh water for even boiler use when broken mains drained storage tanks and sea water contamd. intake reservoir.—*Ed.*

WATER WORKS ANNUAL REPORTS

91st Annual Report (For Year Ending June 30, 1943), Dept. of Water Supply, Detroit, Mich. Dept. operates under 4-man board of water comrs. Estd. pop. of city 1,865,000; pop. served 2,314,540. 415,053 services 99% metered. 28,028 hydrants in city of Detroit only. Water supply from Detroit R. distributed by direct pressure (except for 6 elevated tanks with total capac. of 9.5 mil.gal.) through 4946 mi. of mains by two pumping stations with total installed pumping capac. of 1068 mgd. Water treated in 2 rapid sand filter plants with total rated capac. of 592 mgd. Revenue from sale of water totaled $8,586,731 or $3.71 per capita, $26.98 per acct., $1,736 per mi. of main or

$81.71 per mil.gal. Total operating and maint. expense of $3,590,255 or $34.16 per mil.gal. divided: general plant $0.38; water collection and low-lift pumping $2.13; purif. $3.38; high-lift pumping $7.35; distr. $6.26; repairs and replacements $2.85; commercial $4.22; general expense $7.59. Capital expense of $4,491,056 includes interest of $2,606,911, bonds retired $1,132,000, and sinking fund payments of $752,145. Net cost of works $123,492,089; bonded debt $62,752,738; value of sinking fund $16,173,703; avg. interest rate 4.15%. Income and expenses per 1000 cu.ft. (revenue water basis). Revenue $0.73; operation and maint. $0.305; fixed charges $0.382; net income $0.043. Avg. pumpage 287.90 mgd.; max. 451.11 mgd.; min. 210.90 mgd. Avg. consumption 120 gpd. per capita or 694 gpd. per service. Operation of 2 plants as follows:

Plant	*Water Works Park*	*Springwell*
Purif.—Rating, *mgd.*	320	272
Avg. water filtered, *mgd.*	154	143
Avg. filter run, *hr.*	39.2	36.9
Avg. wash water, %	3.03	4.85
Avg. rate of filtration, *mgd./acre*	145.5	137.0
Avg. chem. dosage, *lb./mil.gal.*		
Alum	88.5	93.2
Ammonia	0.63	0.66
Pre-chlorine	2.45	3.12
Post-chlorine	1.42	1.51
Avg. effluent, *ppm.*		
Turbidity	0.4	0.2
Residual chlorine	0.10	0.11
Free CO_2	3.1	3.8
Total alky.	80.6	78.4
pH	7.7	7.4
Pumping—Rating, *mgd.*	500	568
Avg. pumpage, *mgd.*	149.7	138.2
Coal, *Btu./lb.*	13,846	14,115
Ash, %	8.42	7.56
Coal required to raise 1 mil.gal. 100′, *tons*	805.7	448.7

During year 5724 new services installed, 103 removed; net gain 5621. Nine maint. crews of 4 men each employed repairing 305 broken mains, 182 leaking joints and 915 service leaks. One crew employed repairing broken and leaking gates and cutting out obsolete gates. Hydrant div. inspected 9518 hydrants, repaired 688 leaks, set 124 new hydrants, repaired 110 defective hydrants and thawed 442. Garage maint. force of 6 men cared for 150 cars and trucks, 2 air compressors, 2 tractors and 38 trailers, except servicing which is done by night emergency crew. Foreseeing heavy water demand arising from war efforts, plans made early in '41 for increasing facilities at Springwell station and for major water main extensions. Delay in obtaining preference ratings made it necessary to construct temporary pumping station of 160-mgd. rated capac., with connecting mains for peak-load pumping taking suction from clear well filled during off-peak period. Springwell project contemplated 1000-hp. boiler, 50-mgd. pumping unit, 20-mil.gal. reservoir, 6000-kva. power line, 2 filter units and 750-lb. per day chlorinator, while feeder main project included some 12 mi. of 16″ to 72″ mains. Mains laid 48,381′, discontinued 44,635′; net gain of 3745′ in Detroit. Net gain of 238,276′ outside of city. Avg. number of salaried employees was 482; per diem employees, 578; total 1060. Cost of operation and maint. of 20-story Water Board Bldg. was $102,359 or 92.1¢ per sq.ft. of rentable area. Water Board occupies 7 floors, remainder occupied by various city depts. Sewage disposal system operates under jurisdiction of board.—*O. R. Elting.*

50th Annual Report (For Year Ending September 30, 1943), Munic. Service Com., Wyandotte, Mich. Pop. 32,000. Municipally-owned elec. and water utils. operated by 5-man board known as Munic. Service Com. organized in '26. Comrs. appointed by mayor and confirmed by council, one comr. being appointed each year. Comrs. serve without compensation, re-appointments common; one comr. now serving third term. From 1893 to '25 utils. under supervision of council. Elec. div. had net income of $341,408 or 37.74% of revenue received after all charges, including depreciation, deducted —increase of 6% over previous year. Elec. power supplied increased 18% over previous year. Elec. plant, with depreciated value of $1,871,999, debt free and extension fund of $296,831 invested in federal securities. Cost of elec. energy to consumer: residence 2.6¢; commercial 2.9¢; power 1.8¢ per kwhr., subject to 10% annual dividend. Capac. of plant 18,300 kva., power generated 31,938,900 kwhr. or load factor of 20%. Depre-

ciated plant investment is $102.29 per kva. Annual income is 37% of fixed capital investment. Water div.'s net income, after all charges including depreciation deducted, $64,132. Assets of div. include depreciated plant valued at $1,336,287 and investment of $189,374 in federal funds. Div. income of $203,402 spent as follows: pumping 9.9%; purif. 13.5%; distr. 19.8%; office and admin. 6.2%; interest 11.7%. Other expense 7.4% net income (surplus) 31.5%. Fixed capital (depreciated) $41.76 per capita of $183.56 per customer; operating revenue per customer $27.76. Avg. consumption 3.454 mgd. or 106 gpd. per capita. Max. pumping at rate of 6 mgd. Plant consists of six 1-mgd. rapid sand filters with 1.4-mil.gal. underground storage and 0.5-mil.gal. elevated storage. Pumping capac. of 29.8 mgd. equally divided into 2 pressure dists. Distr. system of 92 mi. of 2″ to 30″ mains serves 746 hydrants and 7280 services.—*O. R. Elting.*

14th Annual Report (For Year Ending December 31, 1943) of the Water Bureau, Metropolitan District, Hartford, Conn. Dist. organized in '29 includes city of Hartford and towns of Bloomfield, Newington, Weathersfield, Windsor and East Hartford. Estd. pop. served 334,000. Consumption 29,664 mgd. or 91.3 gpd. per capita. Gravity supply. Cost of water per mil.gal. delivered: operation and maint. $75.23, fixed charges $76.59; total $152.82. Distr. system of 601.92 mi. of 1″ to 48″ mains serves 38,116 meters and 3920 hydrants. Distr. system extension of 14.5 mi. of mains. 108 hydrants and 1383 meters added to system. This includes Rocky Hill Inc. Dist. which was consolidated with dist. on Jan. 1, '43. Includes 11 mi. of mains, 457 services, 67 hydrants and 450,000-gal. standpipe. Filtered and chlorinated water delivered has pH 6.6; hardness 8 ppm. Income: sale of water $1,612,147; other water revenue $13,398; other income $33,175. Total $1,658,722. Expense: operation and maint. $512,159; depreciation $277,000; taxes $25,234; debt retired $554,522; interest $283,433; miscellaneous $2,098. Total $1,654,448. Transferred to surplus $4,274. Fixed capital $29,701,150; bonded debt $11,094,000. Consumption of over 28 mgd. recorded on 199 days in '43 as against 166 days in '42. Max. rates of 45 mgd. prevailed, based on 6-hr. period.—*O. R. Elting.*

8th Annual Report (1943), Little Rock (Ark.) Munic. Water Works. Pop. of city 98,900; pop. served 123,600. Per capita consumption 72 gpd.; 21,278 consumers, increase of 682 for year and 5047 since Apr. '36 when system installed. System managed by 3-man board of water works comrs. Income of $841,221 exceeded '42 income by $73,589. Fixed assets of $7,330,288 and cash reserve of $777,611 offset by capital liabilities and funded reserves of $6,503,227. Federal grant of $319,002 carried as surplus. Treated water sales equal 90.6% of production. Treated water production totaled 3991.6 mil.gal., while sales of raw water totaled 422 mil.gal. Surface water supply; watershed of 43 sq.mi. Normal rainfall of 48″ furnishes normal runoff of 14 bil.gal. impounded in storage reservoir of 14-bil.gal. capac. 39″ pipeline, 35 mi. long, with capac. of 25 mgd., delivers water to auxiliary storage reservoir of 92-mil.gal. capac. and filtration plant of 15-mgd. capac. Water production for '43 avgd. 10.94 mgd. with max. day of 15.64 mil.gal. Water delivered has total hardness of 24 ppm. Elec. pumping station has rated capac. of 12.75 mgd. Distr. system of 120 mi. of 4–24″ mains and 119 mi. of 1–3″ mains delivers water to 978 hydrants and 21,279 services. Fish rearing pond maintd. at impounding reservoir. Fingerlings placed in pond in May and removed to public fishing grounds in Oct. Single planting of 15,000 fingerlings yielded about 11,000 fish. Breakpoint chlorination to control org. growth in supply pipeline continued throughout year. Effect of chlorine treatment on carrying capac. of main indicates increase in *C* from 120 to 137. In July '42 city divided into 2 pumping zones resulting in considerable saving in cost of pumping. Encouragement of victory garden program by reduced rules for water used from June to Oct. '43 in excess of that used for corresponding period of '42 accepted by 1700 consumers.—*O. R. Elting.*

31st Annual Report (For Year Ending June 30, 1944) of the Pasadena (Calif.) Water Dept. Dept. organized in '12 by purchase of 3 water companies. Since then it has acquired 33 other systems. Estd. pop. 115,000. Water consumption 15.1 mgd. or 131.4 gpd. per capita. WPB restrictions on materials and shortage of labor reduced new constr. to $62,605. Special rate for victory garden irrigation put into effect in '42 continued in '44. As of June 30, '44, 1979

applications for garden rates had been approved, decline of 882 from '43. This rate provides for 6" per mo. at approx. one-half domestic rate. Distr. system, consisting of 368 mi. of 2" to 36" mains, serves 1754 hydrants and 30,125 services. 57% of water obtained from wells and 43% by gravity from Arroyo Seco and Eaton Canyons. Gravity yield nearly double 30-yr. avg. due to two consecutive wet years. Rainfall for '42–'43, 33.33"; '43–'44, 25.53". 62-yr. avg., 20.94". In Nov. '42 electors approved charter amendment appropriating for general city purposes 6% of income from sale of water. Gross revenue was $1,062,335, increase of $39,755 over '42–'43. Operating and maint. expenses $775,865, increase of $13,940. Fixed assets $7,796,927; depreciation reserve $3,033,432; net $4,763,495. Total liabilities $129,909. Surplus of $6,902,675 includes $1,508,500 of federal and munic. bonds to finance emergencies and future constr.—*O. R. Elting.*

Report of the Power System, Dept. of Water & Power, Los Angeles, Calif. (Fiscal Years Ending June 30, 1943 and 1944). Revenue from sale of elec. energy in '43, $37,399,385; in '44, $39,638,917. Operating expense in '43, $14,759,182; in '44, $16,311,984. Net income for '43, $11,296,664, for '44, $11,472,218. Increase due largely to demand of indus. users. Defense Plant Corp., aluminum reduction plant, represented 28.1% of total kwhr. sold in '42–'44 as against 16.7% in '42–'43, with corresponding revenues of 10.5% and 8.3% of total revenue. However, this contract to terminate Nov. '44. June 30, '44, assets of $269,282,547 include plant (first cost) $227,366,610 and $22,938,752 cash. Funded debt $112,901,766. Reserve for depreciation and deferred maint. $49,779,052. Earned surplus $99,000,668; elec. energy generated 3,535,591,692 kwhr. in '43 and 4,134,216,727 kwhr. in '44. Customers 538,887 in '43 and 554,035 in '44; 2.51% increase. Avg. billing price per kwhr.: residential 2.78¢ in '43, 2.50¢ in '44; commercial 1.79¢ and 1.64¢, resp.; indus., except aluminum plant, 0.83¢ and 0.75¢ for '43 and '44. 460,000 residential meters now read bi-monthly; change from monthly reading will result in estd. annual saving of $250,000.—*O. R. Elting.*

Spartanburg (S.C.) Water Works Report (For Year Ending June 30, 1944). Operated under 3-man board of water comrs. Serves city of Spartanburg, Camp Croft and number of industries outside of city engaged in producing essentials of war. Depreciated value of plant $2,324,400; indebtedness $1,194,000; annual income $321,530; operating expense $226,056, or $106.12 and $76.53 per mil.gal. Avg. consumption 8.092 mgd. 8500 meter connections, 206 mi. of mains and 708 fire hydrants inside of city; mains outside of city not listed. New plant put into service in '26 increased normal capac. of 3 mgd. to 6 mgd. Again in '39 plant extensions increased it to 9 mgd. Max. summer consumption of 9.30, 9.15, 10.0 and 10.50 mgd. occurred in '41 to '44 inclusive, as against 5.80 and 5.90 mgd. max. in '39 and '40. Surveys made for expansion in steps as needed to 30-mgd. capac. Reserve of $312,800 set aside from surplus for plant addns. and replacement to increase plant capac. to 10 mgd. by addnl. pumping equip. and settling basin; addnl. storage reservoir; water main constr. Investments totaling $231,000 now available for this work. Net income for year, after depreciation and interest charges, $95,473.—*O. R. Elting.*

Greenville (S.C.) City Water Works. Auditor's Report (For Year Ending July 31, 1944). Net profit from operation $184,324. This compares with $179,073 for '43. Of this sum $160,000 applied to capital charges and $793 to addns. to plant. Value of plant and equip. $5,079,197. Total assets $7,357,886. Bonds outstanding $5,426,000. Assets to apply to bonded debt $2,162,578. Net bonded debt $3,263,422. Surplus (excess assets over liabilities) $1,851,317.—*O. R. Elting.*

35th Annual Report (1944) of the Water Dept., Village of Oak Park, Ill. Water purchased from city of Chicago on metered basis delivered to village at Austin and North Blvd. through five 12" meters. Three other emergency connections assure protection to supply. Pump station at Lombard Ave. and North Blvd. houses 8 motor-driven pumps with combined capac. of 24 mgd., boosting pressures on avg. of 25 psi. Adjacent storage reservoir of 5-mil.gal. capac. Increase of 3.5% in unaccounted flow over '43 due principally to fact that curtailment of critical materials and manpower shortage has prevented close follow-up on leaking services and meter so essential for water conservation. Estd. pop. 69,000; consumption 5.704 mgd. or 82.7 gpd. per capita. 107.4 mi. of mains

supply 12,011 meters and 1135 hydrants; 1 service added in '44. System 100% metered; water sold 85.2% of total. Total income $418,160. Expense: purchase of water $153,405; operation and maint. $85,486; interest $2,495; depreciation $36,575; total $277,961. Transferred to police and fire funds $148,734; net loss $8,534. Fixed assets original $1,264,525; less depreciation $286,134. Liabilities, bonds and deposit funds $78,843. Net worth $482,229.—*O. R. Elting.*

Annual Report (For Year Ending December 31, 1944), Des Moines (Iowa) Water Works. Operates under 5-man board of trustees. Pop. 180,627; consumption 16.95 mgd. or 93.8 gpd. per capita. Water under pressure of 38 to 118 psi. delivered through 429 mi. of 4" to 36" mains (1.3 mi. laid in '44) to 3666 hydrants and to 39,506 services, 99.5% metered 86.8% of water pumped accounted for. Gross income $1,018,567; operation and maint. $395,180; net income $623,387; depreciation $120,687; interest and sinking fund $295,000; surplus $207,700. Plant, less depreciation, $7,446,930; total assets $8,526,388. City's equity $4,452,459. Pumping max. 28.9 mgd.; min. 6.9 mgd.; avg. 16.95 mgd. against 276.955′ head. Coal 15.65% ash; 8921 Btu. as fired. Evapn. ratio 5.69; coal per 1000 gal. pumped 3.52 lb.; boiler and stoker eff. 69.3%; station steam duty 115.49; over-all thermal eff. 9.46%. Tap water avg. 0.671 bacteria per ml. at 37°C. with no coliform organisms. Total hardness: max. 400, min. 260, avg. 231 ppm.; pH 7.35. Rainfall 36.81", 4.83" above normal. Air temp. avg. 51° F., max. 88°F., min. 0°F. Water temp. avg. 55°F., max. 70°F., min. 42°F.—*O. R. Elting.*

Elgin (Ill.) Water Dept.—Statistical Data on Pumpage and Treatment of Water (1944). Total pumpage of 5 stations 2.69 mgd. or 67.1 gpd. per capita avg.; 5.25 mgd. max.; max. rate 9.38 mgd. Avg. rate of filtration 1.84 gpm./sq.ft.; filter runs 134 hr. Water sold 79.1% of water pumped. 67% of all water softened and pumped at Slade Ave. Station. Chem. characteristic at this station for raw and treated water, resp.: phenol alky. 0 and 22.5 ppm.; methyl orange alky. 294 and 105 ppm.; total hardness 278 and 88 ppm.; total normal carbonates 0 and 45 ppm.; pH 7.2 and 9.1. Cost of water softening per mil.gal.: lime $12.53, alum $2.43, chlorine $0.33, oil and coal $1.39, labor $10.07, electricity $3.41. Total $30.16. Over-all cost of all water pumped per mil.gal.: electricity $30.65, labor $27.96, fuel $0.75, plant treatment $11.58. Total $70.94.—*O. R. Elting.*

Annual Report (For Year Ending December 31, 1944) of the Water Dept. of the City of Seattle, Wash. Estd. pop. served 524,265. Estd. consumption 69.42 mgd. or 132 gpd. per capita. Water mains 2" to 96" in diam. total 1153 mi. serving 103,170 services (100% metered) and 10,399 hydrants. In '44, 13.4 mi. of mains, 45 hydrants and 2129 services added to system. Demand for water 6.4% over '43. Operation of water dept. most successful year both from financial and operational view. Peak-day consumption was 147.2 mil.gal., 12% increase over previous high. Unit cost of delivering water lowest on record. Increased vol. and lowered unit costs resulted in all-time high annual surplus of $593,269. Manpower shortage of 25% offset by great devotion of old-time employees. Revised regulations of U.S.P.H.S. required 500% increase in lab. tests. Gross operating revenue $3,094,695; non-operating revenue $53,039; operating expense $731,115, including $100,000 for deferred maint. Net income of $2,412,519 (increase of $204,955 over '43) disposed of as follows: depreciation $616,827; interest on bonds $167,011; amortization of franchise and bond discounts $9,744; budget transfer by special ordinance $250,000; city occupational tax $92,438; sewerage service tax $576,000; general fund service tax $45,030. State util. and occupational tax $67,300 (total taxes $1,030,768), leaving net income of $593,269 added to surplus account totaling $13,056,599 at end of year. Depreciated net value of resources $23,387,432. Outstanding bonds $3,869,000. Tap water: total hardness 24.5 ppm.; pH 7.1; Cl 3.1 ppm. Cost of water delivered per mil.gal.—operation, maint. and depreciation—$53.07; total $100.53.—*O. R. Elting.*

Annual Report, Hamilton (Ont.), 1942. Anon. W.W. Inf. Exch.—Can. Sec. A.W.W.A. **6**: E: 9: 14 (Dec. '44). Data from report of W. L. McFaul, City Engr. Pop. 167,830. Water supply from L. Ontario, subjected to mech. gravity filtration. Max. consumption 31.9 mgd. and avg. 24.57, equiv. to 146.4 gpd. per capita. Avg. pressure 8

psi. Chems. used (lb.): alum 75,775; ammonium sulfate 49,886; Cl 45,542. Wash water 1.9%. Operating cost $780,181.52, including debentures and depreciation, equiv. to 8.7¢ per 1000 gal. Capital expenditures to date $9,787,721.65.—*R. E. Thompson.*

Annual Report, Windsor (Ont.), 1942. ANON. W. W. Inf. Exch.—Can. Sec. A.W.W.A. **6**: E: 10: 16 (Dec. '44). Municipalities supplied: Windsor, Sandwich West, Ojibway, LaSalle, Sandwich East and Riverside. Consumption 82.7 gpd. per capita. 10.8 valves per mi. of main, or avg. of 493′ between each. 113 services per mi. of main. Avg. linear ft. of pipe 46.7′. Great majority metered. 10 hydrants per mi. of main. Raw water pumped 10.93 mgd.; wash water 0.31 mgd. Avg. turbidity 42 ppm. Chems. used: alum 1.3 gpg.; Cl 12,524 lb.; ammonium sulfate 7962 lb. Avg. rate of filtration 124.5 mgd. Water filtered between backwashes 3.8 mil.gal. Avg. filter run 22 hr. 55 min. Increase in loss of head between backwashes 4.6′. Wash water used 2.8%. Gal. filtered per sq. ft. sand per 1′ loss of head, 670. Filters in service 55% of total possible hours—out 1% for backwashing and 1% for maint. Items in water works dollar expenditure: filtering 12.60¢; pumping 18.73¢; distr., maint., etc., 7.86¢; meter reading 1.36¢; admin. 11.54¢; debenture payments 37.40¢; depreciation 2.23¢. Fire protection charges: 1.5 mills on all rateable assessment, equiv. to $68.61 per hydrant. Water rate arrears less than 3%. Book assets $1,870,708.95. Revenue $575,654.55.—*R. E. Thompson.*

Annual Report, Winnipeg (Man.), 1942. W.W. Inf. Exch.—Can. Sec. A.W.W.A. **6**: E: 5: 8 (July '44). Supply from Greater Winnipeg Water Dist., treated with Cl and NH_3. Avg. consumption 16.18 mgd. (71.8 gpd. per capita) and max. 22.42. Pressure 70–75 lb. Unit maint. costs: valves $3.69, hydrants $6.36, services $0.88, meters $0.64.—*R. E. Thompson.*

Annual Report, Brockville (Ont.), 1943. ANON. W. W. Inf. Exch.—Can. Sec. A.W.W.A. **6**: E: 2: 4 (May '44). Avg. daily consumption 2.87 mil.gal., through 3209 services, largely unmetered. Total water revenue $42,942.79. Profit $13,843.45, equivalent to 30% of net income. Total assets $535,378.66.—*R. E. Thompson.*

Annual Report, Guelph (Ont.), 1943. ANON. W.W. Inf. Exch.—Can. Sec. A.W.W.A. **6**: E: 6: 10 (July '44). Supply from springs and deep wells, chlorinated. Avg. consumption 4.14 mgd. (178 gpd. per capita) and max. 4.78. Pumping costs $11.33 per mil.gal.—*R. E. Thompson.*

Annual Report, Owen Sound (Ont.), 1943. ANON. W.W. Inf. Exch.—Can. Sec. A.W.W.A. **6**: E: 7: 11 (Nov. '44). Pop. 14,002. Water supply from river (filtered) and springs (chlorinated only). Avg. consumption 2.34 mgd. (1.43 from spring supply). 167 gpd. per capita. Cost per 1000 gal. 2.13¢. Revenue 3.719¢.—*R. E. Thompson.*

Annual Report, Stratford (Ont.), 1943. ANON. W.W. Inf. Exch.—Can. Sec. A.W.W.A. **6**: E: 1: 1 (May '44). Supply from wells. Pop. of 17,161 supplied through 4537 services, mostly metered. Consumption totaled 650 mil.gal., equivalent to 104 gal. per capita. Cost of water 6.2¢ per 1000 gal., including 1.11¢ for debt charges. Revenue 13.43¢ per 1000 gal. Rates range from 4.5 to 15¢ per 100 cu.ft., less 10% for prompt payment. Min. gross monthly bill 50¢. Total assets $698,526.52, equivalent to $40.70 per capita. Debenture balance $77,500. Surplus $124,543.56. Depreciation reserve $84,502.64. Sinking fund reserve $66,100.60.—*R. E. Thompson.*

Annual Report, Tisdale (Ont.), 1943. ANON. W.W. Inf. Exch.—Can. Sec. **6**: E: 4: 6 (July '44). Water supplied to South Porcupine and Schumacher, former from springs and latter from Mattagami R. Total revenue $65,847.81, including $32,573.47 provided by municipalities from tax levy for debenture debt charges, all expended. Pop. of township 9170. Largely metered.—*R. E. Thompson.*

Annual Report, Welland (Ont.), 1943. ANON. W.W. Inf. Exch.—Can. Sec. A.W.W.A. **6**: E: 8: 12 (Nov. '44). Supply from Welland Canal. Purif. plant includes 2 coagulation basins (0.5 mil.gal. each), 5 mech. gravity filters (1.5 mgd. each), and 2.11-mil.gal. clear water storage. Water supplied to city and Crowland and Thorold Twps. Pop. served 23,135 (15,780 in city). Avg. pumpage 3.12 mgd. Consumption 84.3 gpd. per capita, exclusive of indus. and commercial use. Water delivered through meters 39.9% of total. Avg. Cl and alum dosages 0.9 ppm. and 1.47 gpg., resp. An-

hydrous NH_3, activated C, lime and SO_2 also used. Revenue $86,881.03. Expenditures $80,572.83, including capital charges. Cost of water in cents per 1000 gal.: purif. and pumping 1.885; distr. 0.604; admin. 1.012; debt charges 1.787; bldgs. and grounds 0.390; total 5.678. Total assets $620,186.68. Anal. of latter included.—*R. E. Thompson.*

Annual Report, Woodstock (Ont.), 1943. ANON. W.W. Inf. Exch.—Can. Sec. A.W.W.A. **6**: E: 3: 5 (May '44). Supply from springs, with wells for emergency, chlorinated. Pop. supplied 15,875; 2959 outside municipality. Pressure 80 psi. domestic, 120 fire. Avg. pumpage 1.84 mgd. (120 gpd. per capita) and max. 2.72. Largely unmetered. Total revenue $39,879.01 and expenditures $30,694.82. Total assets $479,355.13 ($37.10 per capita). Surplus acct. $108,042.25.—*R. E. Thompson.*

Annual Report, Dorval (Que.), 1944. ANON. W.W. Inf. Exch.—Can. Sec. A.W.W.A. **6**: E: 11: 20 (Feb. '45). Pop. 3100. Supply from Lake St. Louis. Purif. plant with 1.5-mgd. capac. (U.S.) includes 2 coagulation basins providing 2 hr. 40-min. retention, 4 filters (2 contg. sand and 2 anthrafilt) and chlorinator. Avg. pumpage 0.66 mgd. and max. 1.2. Per capita consumption 200 gpd. Avg. chem. dosages: alum 2.76 gpg. (max. 3.3); lime 0.67 gpg.; Cl 0.35 ppm. Avg. filter run 42 hr.; max. 70, min. 22. Avg. increase in loss of head between backwashes 4.6′. Wash water used 2.25%. Revenue: total $19,131.11; per mil.gal. $79.61; per capita $6.17. Expenditures: total $25,540.12; per mil.gal. $106.28; per capita $8.24. Raw water anal. in ppm.: color 40–80, avg. 50; hardness 40; alky. 30; turbidity 15–30, avg. 25; CO_2 6; pH 6.8–7.3, avg. 7.0. Filtered water: color 0–10, avg. 5; hardness 45; alky. 12; CO_2 10; pH 5.6–6.3, avg. 6.0. Chlorinated water: color 0–10, avg. 5; hardness 60; alky. 45; CO_2 4; pH 7.0–8.0, avg. 7.5. Water temp. 30–70°F.—*R. E. Thompson.*

A.W.W.A. CODE OF PRACTICE

Within the next 30 days, each member of the Association will receive a copy of the Code of Practice, adopted by the A.W.W.A. Board of Directors in January, made up in a form suitable either for framing or for permanent filing. It will be mailed in a tube, without conveying letter, free of charge.

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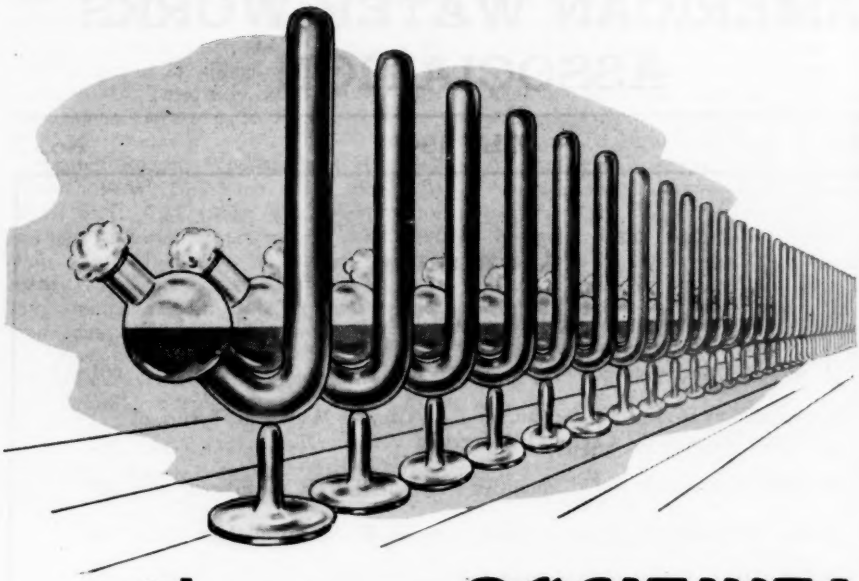

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